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Preface

Progress in oceanography in the past quarter century has been greatly assisted by the development of undersea technology. The National Undersea Research Program (NURP), within the National Oceanic and Atmospheric Administration (NOAA), provides a unique national service by providing undersea scientists with the tools and expertise they need to work in the undersea environment. We equip scientists with submersibles, remotely operated or autonomous underwater vehicles, mixed gas diving gear, as well as underwater laboratories and observatories. How scientists explore under water and examples of what they have found are captured in this report, which summarizes some of the scientific studies the program has supported over the past several years.

The report is titled the Undersea Research Investment in recognition of the benefits that will result from a greater understanding of the world's oceans, which make up more than 99 percent of the living volume of our planet. In spite of its prevalence, the opportunity to observe what occurs beneath the sea is still relatively rare.

The oceans are still a frontier area. The Mid-Ocean Ridge, a mountain range stretching across the ocean basins, was recognized only in the 1960s. Discovery in the 1980s of vents and seeps surrounded by mineral deposits and exotic life that exist without sunlight revolutionized modern scientific theory about the origin and sustenance of life on Earth. NURP-funded scientists are a part of this advance on the frontier.

Research supported by our program spans the undersea environment from the shoreline to the deep sea, capturing nearly all the scientific disciplines. Our hope is that this report provides readers with a glimpse of what's beneath the sea and the breadth of NURP research. Interviews with scientists, as well as staff members based at NURP's regional centers, highlight recent scientific studies that illustrate the significance of gathering information from the ocean, and the delight and dedication associated with ocean research and discovery.

Beyond the glamour of diving on warm reefs or braving the venting of submerged volcanos in a submersible vehicle, experienced scientists must overcome the many obstacles inherent in Earth's harshest environment. Undersea research requires perseverance. The scientists' reward comes from overcoming these obstacles and helping humans understand and live on the "water planet." This report is dedicated to those researchers who have invested in learning about the ocean for our future benefit and profit.

Barbara Moore, Director
National Undersea Research Program

Introduction

NURP/UCAP

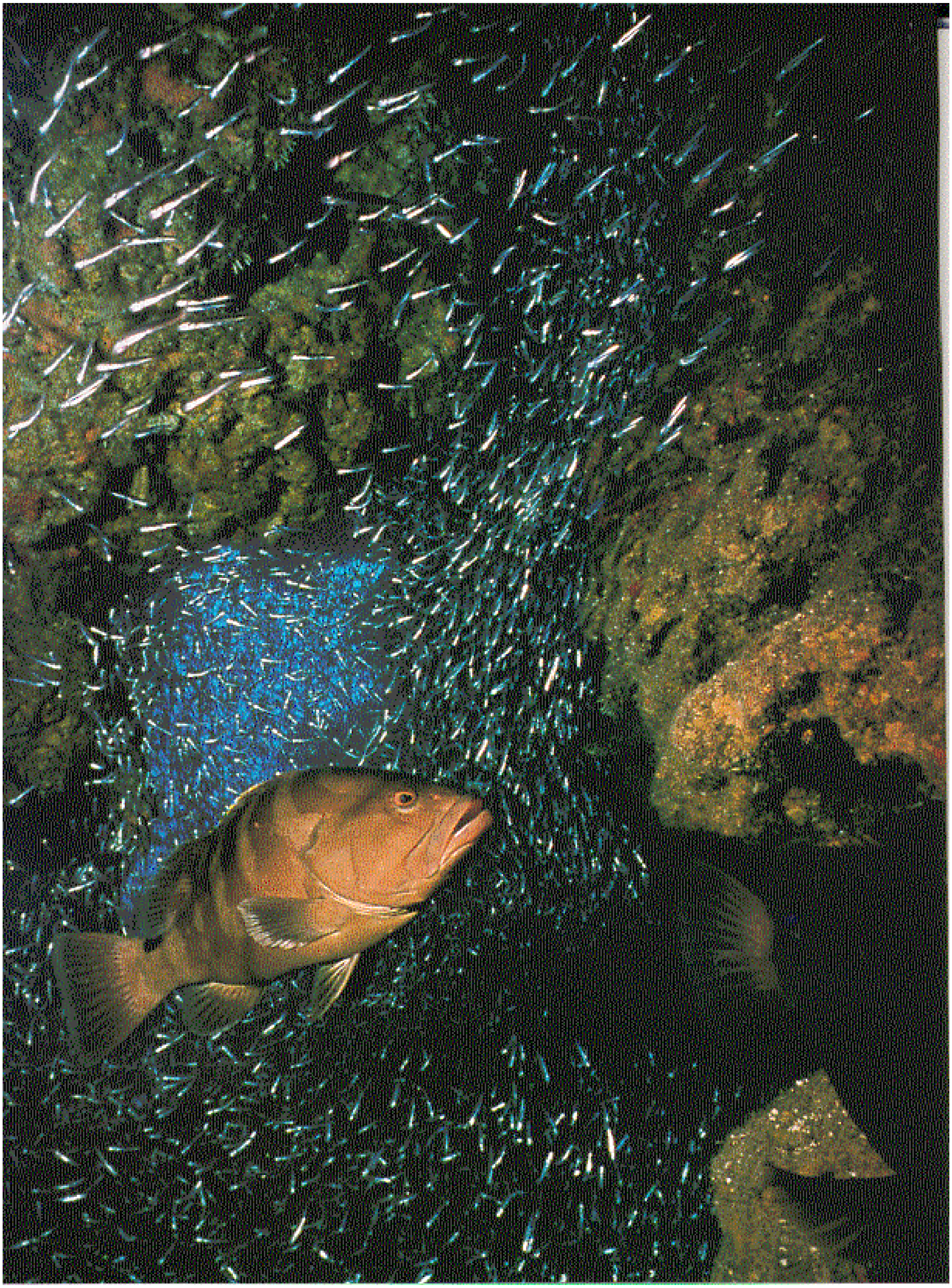
The *Delta* submersible on the *McGaw.*

The National Undersea Research Program is part of the research arm of NOAA. Its mission, briefly put, is to identify important questions that can be addressed through research under the sea, and to provide the tools and expertise necessary to get scientists underwater to carry out their research.

The oceans are important. Efforts to gain an understanding of what they contain and how they function is an investment in the future. This report uses examples drawn from recent projects carried out through the program to illustrate the wide breadth of undersea research in progress. Any attempt to catalog the wide range of scholarly research supported by the program would be a long and tedious tome. Instead, we have chosen to describe a selected set of projects as illustrative examples—easily readable research snapshots—along with explanatory material showing the relevance and contributions of the projects for a more general audience.

We strive to have a high quality scientific program. Projects are selected for funding on the basis of their scientific quality as well as relevance to national and NOAA research needs. A complete listing of all projects funded for Fiscal Year 1995, 1996, and 1997 appears in Appendix I. Scientific results have been published through appropriate scientific and technical journals.

Appendix II provides information on the organization of the National Undersea Research Program and its six national undersea research centers.



Sustainable Fisheries

From the Gulf of Alaska to Gulf of Maine, NURP scientists are descending in undersea vehicles to study the world's most productive fishing grounds. Through the viewport of a submersible, NURP scientists observe where and how fish live and record more precisely how many fish exist at these depths. While important harvested species are in decline, their recovery may be impeded because their habitats are threatened by human activities as well as other factors. This information is of increasing interest to fisheries managers who consider essential habitat a critical factor in protecting marine resources and as a resource to be managed. Fisheries management and conservation also depends on knowing what naturally regulates the abundance of marine fishes.

This chapter focuses on identifying the key habitats of critical species, and what physical and biological processes are responsible for their survival and sustainability.

Nassau grouper.

Fishing Gear Impacts

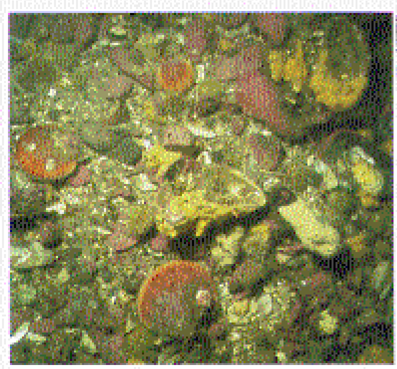
From the Gulf of Maine to the Gulf of Alaska, researchers are descending in undersea vehicles to study remote and rugged environments where important fish stocks live. Some of these fish–cod, flounder, and grouper to name a few–are in decline. Their recovery may be impeded because their habitats have been degraded or destroyed by human influence. Just as some animals take refuge in the African prairie grass to hide from lions, some marine fish take refuge in places like coral reefs, shipwrecks, sea grass, worm tube mats, sponge-covered gravel, forests of anemones, or mud burrows to hide from bigger fish. Computer models indicate that reductions in habitat complexity reduce survival of juvenile fish, especially during periods of low population size.

In several recently funded NURP studies, fisheries biologists have been trying to determine the effects of fishing and fishing gear on juvenile fish habitats and on the survival of harvested species that live within the U.S. Exclusive Economic Zone. Submersible vehicles have given these scientists more precise estimates of fish abundance and habitat requirements.

In the Gulf of Maine, mobile fishing gear has reduced seafloor habitat complexity, according to Peter Auster, a NURP fish ecologist. Auster and colleagues from the Sea Education Association, University of Maine, Maine's Department of Marine Resources and U.S. Geological Survey in Woods Hole used a remotely operated vehicle (ROV), submersible and sidescan sonar to study the impacts of trawling on habitat. The researchers found that trawling reduces habitat complexity by removal of benthic fauna such as sponges, smoothing of sand ripples, and removal of species like crabs that produce depressions and burrows. Fishing gear impacts also reduced biodiversity, which may alter the number and variety of species in a community. The effects of these disturbances to the food web, and to fish production, can only be roughly predicted, Auster said.

Continued studies during the past two years have focused on NOAA's Stellwagen Bank National Marine Sanctuary. Auster and his colleagues used an ROV to link fish distributions to a range of underwater habitats. The fish and the different kinds of seascapes they live in were identified using multi-beam bathymetry and sidescan sonar. Habitats, based on their ecological value to fishes, were then classified by researchers to provide a baseline of information for a long-term habitat monitoring program at the sanctuary. These studies have raised further questions about the amount of fishing effort required to change habitat integrity for particular species, and what kinds of measures could be used for repairing habitat damage in the future. "Understanding how fishes, especially juveniles that are more vulnerable to predators, use particular habitats leads us to an understanding of how to manage habitat for sustaining harvested fish populations, as well as the related objective of sustaining biodiversity of non-harvested species," said Auster.

To better determine the impacts of scallop dredging on the fish habitat of Northeastern Georges Bank, a multi-year NURP study by



PETER AUSTER

Examples of disturbance to the seafloor produced by a single pass of a scallop dredge at a coastal site in the Gulf of Maine (20 m depth). The images are before and after images from a cobble-shell habitat. The sponge colonies that stabilize the shell aggregates are removed in the impacted state.


PETER AUSTER AND PAUL DONALDSON

Red fish.

researcher Jeremy S. Collie of the University of Rhode Island is now in place. A stark contrast was observed at undredged sites versus dredged sites by Collie. Undredged sites were composed of hydrozoans, bryozoans, and tube-dwelling polychaetes called epifauna, which make complex habitats for small animals. At dredged sites, epifauna and small animals are almost entirely absent, and predators and scavengers are abundant, Collie said. In a heavily disturbed area of Georges Bank, which had been closed to fishing since December 1994, there were initial signs of recovery, according to Collie's observations during 1996 and 1997. New colonies of epifauna had emerged and juvenile scallop populations were on the increase. This year, Collie will use side scan sonar, video, and still photographic imagery of the seafloor to continue to document the recovery of the area closed to fishing compared with areas where bottom fishing continues.

Historically, clam dredge surveys have been used to describe the habitat requirements of fish and shellfish and quantify their abundance. The results of these surveys produce mixed results with only a very broad determination of fish distributions, variances in estimates of mean abundance, and inadequate sampling of recently settled juvenile fish, said Robert Cowen, a fisheries biologist of the State University of New York at Stony Brook.

Last summer, NURP provided some valuable undersea research tools for evaluating the efficacy of hydraulic dredging used in stock assessments for commercially important species of clams.

"There had been suggestions that hydraulic dredges used to contact clam stock assessment surveys weren't working the way they were supposed to to catch clams,"said Waldo Wakefield, a fisheries biologist with NURP's Mid-Atlantic Center. During a stock assessment of two valuable commercial clam species, surfclams and ocean quahogs, in the New York Bight by NOAA's National Marine Fisheries Service's (NMFS) Northeast Fisheries Science Center last summer, Wakefield helped facilitate the center's use of some new undersea sensors to insure the clam dredge was doing its job. Technology developed by NMFS, including an inclinometer for measuring whether the dredge was making contact with the bottom, as well as video cameras for monitoring the dredge's performance, was used in the New York Bight.

"Sometimes a picture is worth a thousand words," Wakefield said. The *in situ* sensors allowed fisheries managers to quantify the performance of the dredge, while the overall operation of the dredge was monitored by an undersea video camera along for the ride recording footage of the dredge in operation.

The effects of fishing can have a more serious impact. In the Caribbean, Florida, and the Gulf of Mexico, anglers have learned where and when to find grouper spawning aggregations. These fish do not spawn continuously, so wiping out an aggregation may eliminate a whole generation of fish in a region. In 1994, this targeted fishing prompted the South Atlantic Fisheries Management Council to set aside a no-fishing zone in the Oculina Reserve (named for its oculina corals) off southeastern Florida. In 1996, using a NURP-supported submersible and side-scan sonar, fisheries biologists Churchill Grimes of the National


CMRC

Black volcanic sponge.

Marine Fisheries Service in Panama City, Fla., and Chris Koenig of Florida State University, surveyed and described fish distributions and habitat conditions in the Oculina Reserve. Most reef fish dependent on the Oculina coral for habitat, including snowy grouper, black sea bass, and amber jack, suffered a drastic reduction since the sites were surveyed a decade ago, the scientists observed. In addition, coral had been heavily damaged from trawling and dredging. Where some dense branches of coral once stood a foot tall, all that remained was rubble and thumb-sized coral. In 1999 and beyond, new technologies such as laser line scan systems will provide faster, better habitat surveys to aid their long-term monitoring efforts.

Shellfish and Fish Habitat

Invertebrates that grow on cobbles and boulders also provide cover for juvenile fish and shellfish such as cod and lobster. Today, lobster is the single most important regional commercial species in the northeast United States. Lobster grosses more than 100 million dollars in landings and employs 10,000 lobstermen in the State of Maine alone. Overfishing and fish nets dragged along shallow cobble bottoms in the Gulf of Maine–the only habitat where New England lobsters have their nursery grounds–threaten the lobster harvest. By counting the number of baby lobsters that have just arrived there, fishermen have a good estimate of what landings will be like for the next seven years, said Robert Steneck, a marine biologist at the University of Maine.

Steneck, who studies the complex life cycle and ecology of lobsters, has used NURP support, submersibles, and scuba diving, to observe the habitats that lobsters occupy during different stages in their life. From cobble nursery grounds, juvenile lobsters move to boulder fields and kelp beds, and then as mature adults to deep waters offshore. Oceanographic circulation patterns, observations by lobstermen, and data from NMFS support the hypothesis that reproductive age lobsters are concentrated in near-shore, deep-water habitats in the northeast corner of the Gulf of Maine. Finding out where lobsters live is one of the mysteries researchers set out to solve with NURP support in 1997. The *Johnson-*

The lobster's life history remains a mystery.

Sea-Link submersible enabled Steneck to observe lobsters directly in their range of habitats throughout the Gulf of Maine. The work augmented traditional stock assessment approaches, and confirmed that significantly more lobsters live nearshore in deep waters off the eastern Maine Coast than previously thought.

Still, parts of the lobster's life history remain a mystery. Lobsters are the only fishery in the world that has been aggressively harvested for more than a century and has not only remained stable, but stocks have increased. "One theory is that the lobster broodstock are living in a refuge," Steneck said, "relatively immune to being harvested. This would explain why the resource, harvested for the past 150 years, has been stable or has increasing populations." If the refuge where the reproducing broodstock lives can be identified, fisheries managers have a better chance of protecting it, he added. An earlier project to quantify the abundance and location of reproductive lobsters by Steneck led to the discovery that a segment of lobsters that live on Georges Bank have migrated there from other habitats as far away as Nova Scotia and New Hampshire. *In-situ* studies to piece together the life history phases of the lobster along with the physical oceanography of the Gulf of Maine present a unique opportunity to understand one of our important marine resources, Steneck said.

NMFS biologist Mary Yoklavich used the *Delta* submersible, a two-person shallow diving submersible that dives to 370 m (1,200 ft), to explore rockfish living in the rocky outcroppings of Monterey Bay, California. Rockfish, named for their preferred habitat, are one of the most popular commercial and recreational fish on the west coast. They also fascinate fisheries biologists because of their diversity and longevity–there are 57 species of rockfish on the west coast alone, and some can live to be more than 100 years old. Their longevity, late maturation, and rugged habitat make them difficult for fisheries managers to assess and manage. Yoklavich used sidescan sonar to precisely describe the seafloor in portions of Monterey Bay canyons, and video cameras mounted on the submarine to count cryptic rockfish tucked in canyon walls. What Yoklavich found was an astonishing population of rockfish that far exceeded the rockfish populations living in more exposed canyons exploited by fishing. The habitat appeared to provide rockfish with greater protection from fishing. Fisheries biologists Victoria O'Connell of the Alaska Fish and Game, NURP's Waldo Wakefield, and Gary Green of Moss Landing Marine Laboratories used similar techniques to census rockfish habitat along the Alaska coast with NURP funding.

Rockfish.

NURP-funded oceanographer Eric Vetter of the Scripps Institution of Oceanography also discovered that habitat plays a role in fish abundance during his study of microbial food webs in Scripps Canyon off the coast of La Jolla in southern California. Using the *Delta* and the submersible *Sea Cliff* in 1996, Vetter found significantly more fish including sablefish, dover, sole, and Pacific hake at all depths inside the canyon than outside the canyon. A slurp gun attached to the submersible vacuumed up samples of kelp, surf grass, and detritus accumulating in the canyon, which appear to support the smallest organisms at the base of the food chain that larger fish need to survive, Vetter said.

With the recent advent of manned submersibles and ROVs equipped with high resolution cameras, the problem of collecting data on juvenile fish has improved, Auster said. In a two-year study beginning in 1997, fisheries biologists Cowen and Kenneth Able of Rutgers University Marine Field Station received NURP support to evaluate what habitat qualities are critical for juvenile fishes living in shell beds off New Jersey. By conducting surface trawl efforts in combination with *in-situ* observations, the researchers have a powerful tool for estimating juvenile fish densities in association with specific habitats, information local fishery managers use to protect the fishery. The results of the project will also be used to help evaluate the potential impact of fishing practices, such as scallop trawling, on benthic community structure.

Based on the evidence that habitat plays an important role in fish abundance, some fisheries biologists are recommending a different management approach, which is prompting action by some fisheries management councils. Auster and his colleagues have been advocating use of a precautionary approach to habitat management. Setting aside no-fishing areas in all habitat types from mud to boulders would enable assessments of the effects of fishing on habitat resources.

"Our management of marine resources has to go beyond looking at the abundance fluctuations of species,"Cowen said. "We have to look at the entire marine ecosystem, and part of that is habitat." All of the Fishery Management Councils will be addressing the need to designate and conserve essential fish habitat as mandated under the Sustainable Fisheries Act. NURP-supported research will be used in making these decisions. The challenge will be to not only translate the results of completed research into useful information for fishery managers, but to continue to fund high quality studies that support management needs into the future.

Healthy Oceans

Clean air, water, and land are valuable commodities that need to be managed. Our estuaries and coastal waters are now subject to increased pollutants as a result of agricultural uses and the disposal of industrial and domestic waste. A major problem of the 21st century will be deciding what to do with the vast increases in waste of a growing population—forecast to double from six billion in the next century.

Healthy coastlines that support life and property, tourism and trade depend on the preservation of natural resources and the protection of clean air and water. The Florida Keys serve as an example of a valuable national asset that is under increasing pressure from both man-made and natural threats. Teasing out the natural versus human-caused disturbances so that coral reefs can be managed effectively is gaining momentum in Florida now.

Since the ocean comprises 98 percent of the free water on Earth—and healthy coastlines depend on it—determining the many components present in seawater is a key thrust of scientific research sponsored by NURP. The discovery that the deep sea may be as species-rich as a tropical rainforest comes at a time when pressure is mounting to use every available square foot of coastal land for development. As the number of land sites dwindles, the oceans are likely to become more prone to waste management in the future.

NURP researchers in this section discuss what they've learned about the effects of dumping on living resources and deep-sea biodiversity, as well as their concern about transmission of contaminants back to the human population. They will take you on a cruise to 20 coral reef sites from south of Miami to the Dry Tortugas to understand why the Florida reefs are doing so poorly in some places. They also discuss the effects of coastal development and natural processes, which circulate material from land into our rivers, bays, to the bottom of Lake Michigan and the continental shelf of the Atlantic Ocean. In deeper waters adjacent to Hawaii, using the opportunity presented last year when the submarine volcano Loihi off the big island of Hawaii erupted, they report effects on ocean chemistry.

In this chapter, NURP researchers focus on implementing more efficient ways to observe, monitor, and determine the ecological status of ocean resources.

Schoolmaster snapper.

Coral Reefs

Status of Reef Resources

On the surface, it might sound like a glamorous tourist package to dive the Florida Keys—a cruise to 20 coral reef sites from south of Miami to the Dry Tortugas. On closer examination, the cruise turns out to be a lot of hard work methodically counting plants and animals to assess changes in Florida coral reefs, and comparing reefs to see how they are faring relative to one another.

Most people don't know that Florida has the third longest coral reef system in the world, visited by more than a million divers each year—the centerpiece of a thriving $1.2 billion annual tourist business. A major NURP-led research effort is underway by scientists and resource managers to understand why the reefs are doing so poorly in parts and to protect them from further harm.

Trying to determine what causes reefs to change is a difficult riddle to solve. Since a cold front swept down the Florida peninsula in 1975 and wiped out staghorn and elkhorn corals virtually overnight, Florida reefs appear to be on a decline that has not slowed in 20 years. Hurricanes, cold fronts, heat waves, marine disease epidemics, excess nutrients close to shore, fishing pressure, and ship groundings have all factored into the descent of corals. Congress established the Florida Keys National Marine Sanctuary in 1990 to understand those threats and to protect the coral reefs from over-exploitation. In July 1997, the National Marine Fisheries Service (NMFS) issued draft regulations to protect essential fish habitat—a move that sanctuary managers hope will lead to additional no-take fishing zones in the Keys where populations of important commercial and recreational fish are depleted.

What should a thriving, healthy reef look like? Warm emerald colored waters and tropical fish darting about rock formations are images we associate with coral reefs from travel brochures and television documentaries. Called the rainforests of the sea for their complexity and diversity of life, coral reefs are actually built by minute coral polyps that secrete calcium carbonate.

Most of the coral reef research to date has been done on shallow reefs in less than 20 m (66 ft) of water. In addition, no studies had looked at reefs throughout the Keys 360 km (220 mi) reef tract at the same time. In an effort to better evaluate the condition of deeper coral reefs and associated communities, a team of marine scientists embarked upon an ambitious Keys-wide expedition in 1995 with support from NURP, the Marine Sanctuaries Program, the National Park Service, the Munson and Macarthur Foundations, and Harbor Branch Oceanographic Institution. The research team was led by Steven Miller, associate director of NURP's Southeastern United States and Gulf of Mexico Center, and included Richard Aronson, a senior marine scientist at Dauphin Marine Science Lab, John Ogden, a marine ecologist with the Florida Institute of Oceanography, and Jim Bohnsack, an NMFS fisheries biologist.

What immediately impressed the researchers on the cruise as they began to compare coral reefs on a regional and local level were the "huge differences" in reefs, even if the reefs were fairly close to each other. "It wasn't always obvious why that should be," Aronson said. At sites throughout the Keys, researchers considered factors such as how many different


E. JOHNSON

Schoolmaster snapper.

kinds of coral, fish, and shellfish were present and how abundant they were, and whether or not there were signs of disease. The researchers on the Keys-wide cruise observed coral diseases, coral bleaching, excessive algae cover, and fewer fish at several of the reefs. The Dry Tortugas, west of the Florida Keys, appeared to be the exception. “The obvious hypothesis for why reefs are doing better in the Dry Tortugas,” Aronson said, “is that they’re untouched by man.” The most remote reefs are removed from poor water quality associated with coastal development, Miller added.

In the Dry Tortugas, scientists found more star coral (*Montastraea* and *Siderasterea*), and less disease (though it has since been found in high abundance at a few sites). In the Middle Keys, there appeared to be a relationship between how close or exposed reefs are to Florida Bay waters and how well they are faring. Reefs opposite bay channels are more exposed to colder, less salty, nutrient-rich waters, and appeared to be doing worse, Aronson said.

Since the coral reefs examined were at deeper depths and less exposed to fishing pressure (especially spear fishing), NMFS scientists on the Keys-wide cruise expected to find more economically valuable fish, but this didn’t prove to be the case. “Most of us were surprised by how few economically important species we saw at those depths,” Bohnsack said. “There were fewer grouper, snapper and grunt—the three big targeted fishing groups.” Yellowtail was the most abundant snapper with the highest density in the Middle Keys and the lowest density in the Upper Keys. Few grouper were observed, although the highest densities were observed in marine protected areas with either no spear fishing or no commercial fishing, Bohnsack said. Compared to shallower reefs, algae and coral-eating fish like parrotfish and surgeon fish dominated the deeper reefs.

Why are there more predatory fish in shallower coral reef environments where there is more fishing pressure? Why are there fewer predatory fish and more herbivorous fish and macroinvertebrates on deeper reefs? There are hypotheses that need to be tested in the future. “It could be overfishing,” said Ogden. “There are very few large predators on the reefs, and when little fish are released from predation their populations grow. These fish take over areas of coral and kill it by nibbling away at it, and on dead coral, algae grows.”

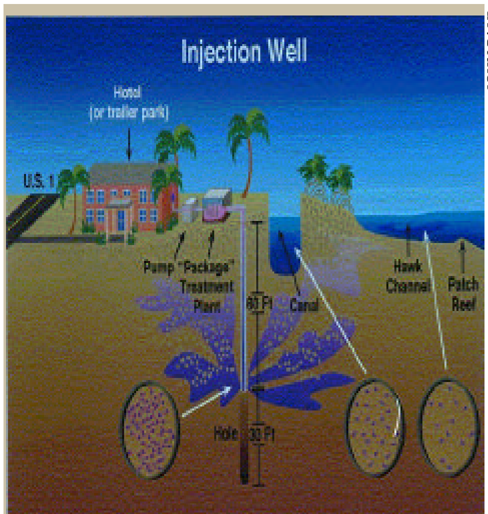
Water Quality

Another mystery that NURP-funded researchers have set out to solve is whether or not nutrients like nitrogen and phosphorus from sewage effluent, agriculture and urban runoff that appear to have harmed nearshore reefs are making their way out to offshore coral reefs. Excess nutrients act like fertilizers and promote growth of algae that may smother some coral reefs. Wastewater from injection wells and septic tanks in the Florida Keys are found in surface marine waters and could be part of the problem. With no centralized wastewater disposal system in the Florida Keys, except for Key West, residents depend on more than 30,000 injection wells, septic tanks, and cess pits. Since 1993, John Paul and Joan Rose, marine microbiologists at the University of South Florida, have studied the impact of these waste disposal systems on Key Largo. Similar studies are also being conducted by Eugene Shinn, project chief of the U.S. Geological Survey, who installed monitoring wells in the Keys, including at NURP’s *Aquarius* habitat at Conch Reef, to test for contaminated groundwater in the marine environment.

Typically, bacteria migrates only a short distance from a septic tank’s drain field, but this doesn’t always happen in the Florida Keys where groundwater permeates through the cracks and fissures in the porous limestone bedrock. Measurements of the rate of bacterial migration from its original source to offshore reefs were as fast as 20 m (64 ft) per hour in some of Paul’s experiments.

Paul and Rose used a harmless viral tracer to test whether fecal bacteria from injection wells were moving through groundwater into the marine environment. Bacteria flushed down toilets in domestic residences showed up within eight hours in groundwater, and within 36 hours it was detected in Florida Bay. By 53 hours, the tracer appeared in a canal on the other side of the highway, on its way to Hawk Channel and the Atlantic Ocean. A second experiment indicated that the tracer could move from the waste disposal well to the canal in less than eight hours if strong north winds occurred at the same time.

“We conclusively showed the connection between wastewater disposal practices and the marine environment,” Paul said.



JOHN PAUL

NURP researchers used a harmless viral tracer to test whether fecal bacteria from injection wells were moving through groundwater into the marine environment. Bacteria flushed down toilets in domestic residences showed up within eight hours in groundwater, and within 36 hours they were detected in Florida Bay.

Natural Variability

Clouding the issue of reef protection are natural factors that affect reefs, for example, variations in climate and water temperature. Conch Reef, eight miles southeast of Key Largo, is removed from the pollutants that Paul detected closer to shore. Bathed in the clear, clean waters from the Gulf Stream, Conch Reef provided marine ecologists Jim Leichter and Mark Denny of Stanford University with an ideal test site for studying natural factors that influence the growth and survival of corals.

The researchers discovered that internal waves push cool water up onto the reef tract from a seaward direction, bringing with it a high concentration of dissolved nitrogen and phosphorus. These nutrients can influence the growth of benthic algae harmful to reefs quite apart from sewage-derived nutrients introduced from shore. Rapid temperature fluctuations—on the order of more than five degrees within a few minutes—are also problematic for corals.

Just as fewer predatory fish were found at deeper reefs where researchers assumed there would be more fish, a surprising result of this research was that temperature and nutrient variation increases with depth. Previously researchers thought deeper reefs were exposed to relatively constant conditions compared to shallow reefs, which are exposed to variable sunlight, temperature, and breaking waves. These findings show that some of the most common assumptions can be wrong. "Our work reveals aspects of the environment that you could never observe from the surface," said Leichter.

To understand how humans affect coral reefs, it's critical to understand what naturally influences their survival. Separating the difference between natural variations and human-induced influences is extremely important, especially in regions like Florida where the coral reefs are located toward the northern limit of where it's possible for them to grow and where natural baseline variation may be very high. Since Florida's reefs are already a marginal habitat, reefs have developed adaptations to the physical environment–survival mechanisms that scientists are just beginning to understand. At some point, the combination of both natural and man-made influences can tip the balance against the well-being of corals.

The effective management of reefs will depend on this understanding of how natural and human influences impact reefs.

Cycling of Materials

Contaminants

The unique chemical properties of water make life possible on Earth. Understanding the chemical constituents of seawater and their distribution is important in order to determine such things as the fate of contaminants in the environment, the critical role that chemical constituents play in the production of organic matter, and their impact on marine life. To get a better picture of how ocean chemistry operates, scientists supported by NURP are studying the effects of coastal development and the natural processes that circulate material from the land into our rivers, bays, to the bottom of Lake Michigan, and the Atlantic and Pacific Oceans.

Undersea technology helped scientists advance analytical chemical techniques and sampling methods to learn more about the correlation between coastal and biological processes and chemical constituents in the ocean. Lake Michigan serves as an ideal laboratory for studying chemical processes because the flushing time for sediments in the Great Lakes averages about 100 years, compared to the mixing time of the ocean that occurs on a scale of up to 1,000 years. J. Val Klump, a biogeochemist with the Center for Great Lakes Studies, received NURP support to study what happens to chemical constituents once they settle out and enter the bottom sediments. Lake Michigan is subjected to the pressures of an industrial and agricultural coastline. With its paper mills and dairy farms, the lake is the ultimate recipient of anthropogenic nutrients that fuel anoxic conditions in nearby Green Bay.

A remotely operated vehicle (ROV) used benthic chambers for collecting bottom sediments. “Without this information, it would be impossible to understand the system,” said Klump, who designed the sampling system. Cesium 137, a radionuclide used in chemical weapons testing in the 1970s, serves as one excellent tracer for looking at how sediments get mixed by worms, amphipods, fish, and storm events. These physical processes appear to play an important role in the resuspension of chemicals like ammonia, organic nitrogen, and carbon dioxide.

His research findings also have implications for how pollutants cycle through the Great Lakes and marine environments. “The good news is that contaminants are rapidly transported to the sediments where their concentrations are reduced,” Klump said. “The bad news is they’re entering into a long-term box, which continually exposes the overlying water to the contaminant.”

Carbon Cycling

Scientists around the world are trying to understand the role that the ocean plays in regulating the amount of carbon dioxide in the atmosphere, and the manner in which the ocean responds to increases in atmospheric carbon dioxide as a result of the burning of fossil fuels, deforestation, and other anthropogenic sources. Unlike the open ocean, the cycling of carbon in the coastal ocean is difficult to understand because it varies with large seasonal shifts in the productivity of marine life, as well as the immediate exchange of materials between the seafloor and the surface.

To understand how carbon cycles through the ocean, scientists must first know how all the elements that impact carbon distribution and forms interact, said George Luther, a chemical oceanographer at the University of Delaware. Toward achieving this goal, chemical oceanographer Clare Reimers of Rutgers University and Luther pooled their array of technical electrode designs to take *in situ* measurements of pH, dissolved oxygen, manganese, iron and sulfide in coastal sediments of the New York Bight in 1997 with NURP funding.


J. VAL KLUMP
Green Bay, Lake Michigan.

“When you see black on a banana, that’s decomposition,” Luther said, “but we can’t see that going on at the bottom of the ocean.” Using an ROV with *in situ* probes (gold wire electrodes with a thin coat of mercury), the researchers are able to measure the concentrations of dissolved oxygen, iron, manganese and sulfide in coastal sediments. As phytoplankton in surface waters die, they rain down to the sediments at the bottom where they are decomposed by bacteria. The researchers observed that bacteria consumed all the oxygen within the top 0.8 in (2 mm) of the sediments. In order to decompose organic matter residing deeper in the sediments, the bacteria use manganese oxides and nitrate to about 1.2 in (30 mm). Iron oxides are used deeper down, and then sulfate. “This is important in the cycling of carbon in the ocean,” Luther said. “There’s so much organic matter being produced and cycled in the coast, that the predominant oxidant may not be oxygen anymore—it may be manganese or iron oxide or sulfate. We still don’t know all the intricacies of these interactions, and how they effect the global carbon budget.”

The researchers have most of the tools for measuring organic matter decomposition in coastal sediments. Luther hopes that an autonomous underwater vehicle (AUV) with electrode sensors will be used in the future to measure chemical processes in deep ocean sediments where the concentrations in chemicals are less than the coastal ocean. Since the continental slopes and deeper waters constitute 93 percent of the sea, estimating the fate of materials and how long they take to move around the deep ocean, and their effect on the environment is an important area of ocean research.

Hydrothermal Vent Fluids

An ideal opportunity to use the deep ocean as a laboratory for understanding ocean chemistry arose recently when the submarine volcano Loihi off the big island of Hawaii erupted. A pervasive flow of minerals, including copper, iron, manganese, zinc, potassium, and calcium, streamed out of the mounds and hydrothermal chimneys of Loihi. NURP scientists were able to visit the site within days to begin investigating the nature of fresh vent fluids. Loihi along with other ridge and vent fields, provide most of the mineral resources on Earth. The timely Loihi eruption gave NURP researchers a "geochemical telescope" into the Earth's mantle to sample how minerals are formed, said Alexander Malahoff, director of NURP's Hawaii and Western Pacific Undersea Research Laboratory, who led a series of dives to Loihi.

Chemicals in the vent fluid also support huge swarms of microorganisms that festoon themselves on rocks like white teeshirts flapping in the water. During several dives to Loihi two years ago researchers would observe huge bacterial mats that would disappear from one day to the next when rubble would prevent magma from interacting with seawater. "It was kind of scary," said microbiologist James Cowen of the University of Hawaii. "You'd go back the next day and the bacteria were gone from one site, but found further away."

Vents provide a continuous supply of minerals and gases such as carbon dioxide and hydrogen sulfide that have played a major role in the evolution of the oceans and atmosphere, and conditions favorable for life. These are topics of other NURP projects.

The tools NURP scientists are developing to take more systematic measurements of the distribution of chemical constituents in the ocean and in sediments are also useful in other coastal ecosystems. By continuously monitoring the ocean over large spatial scales, as researchers are doing at LEO-15 (and plan to do this year at Loihi at a Hawaii Undersea Geo-Observatory), researchers may eventually be able to forecast hypoxic or volcanic events. Developments in ocean chemistry are enhanced by rapid advancements in technology. This underscores the importance of technology in the context of the global environment.

Deep-Sea Dumping

The discovery that the deep sea may rival tropical rainforests in the diversity of life comes at a time when pressure is mounting to use every available square foot of coastal land for development. A major problem of the 21st century will be deciding what to do with the vast increases in waste produced by a growing world population—forecast to double to 12 billion in the next century. The effect on the oceans must be understood for the good of the public, and national and international decision and policy makers. As the number of


TERRY KERBY

Schematic of *Pisces V* moving along the north wall of Pele's Pit at the undersea volcano, Loihi.

landfill sites dwindle, the oceans must be evaluated as a possible option for disposal of a larger fraction of human wastes. At present, most waste disposal in the ocean is banned by national policy and international law as a result of the environmental abuses since the industrial revolution.

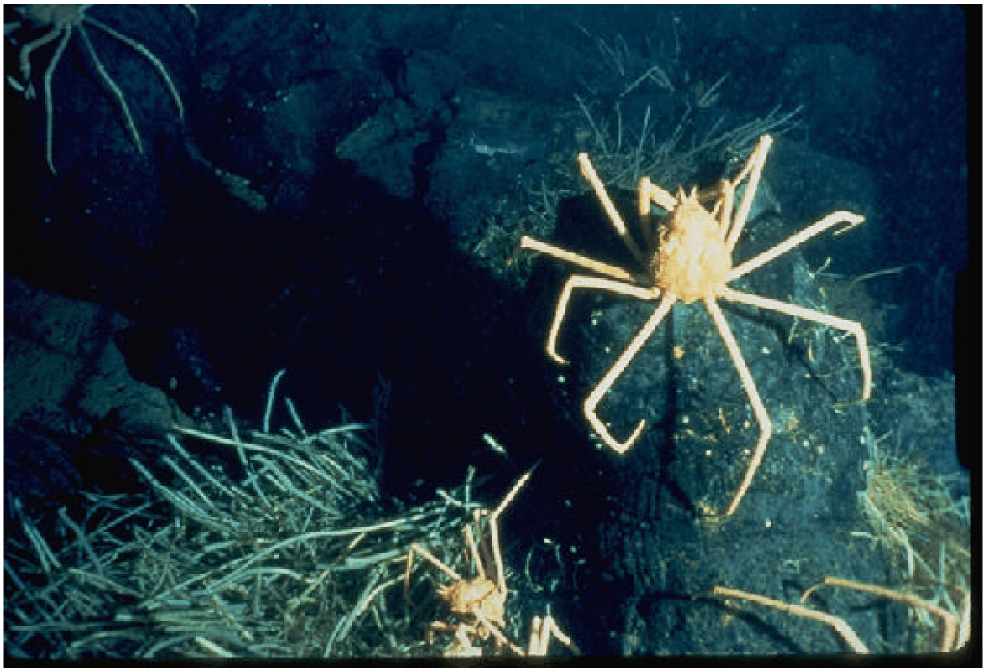
With more than 80 percent of the ocean at depths of more than 3,000 m (9,840 ft), the deep-sea floor seems safe from the man-made disturbances that threaten terrestrial and coastal environments. But is it? NURP recently supported numerous projects in the oceans and Great Lakes to determine the impact of waste disposal on bottom-living animals. Of particular concern to researchers are the effects of dumping on living resources and deep-sea biodiversity, and the possible transmission of contaminants back to the human population.

In the most detailed study ever done related to the impacts of ocean dumping, NURP-funded scientists led by benthic ecologist Fred Grassle of Rutgers University and geochemist Michael Bothner of the Woods Hole U.S. Geological Survey documented the impact of 42 million tons of wet sewage sludge dumped at the 106-Mile Dumpsite, 106 nautical miles southeast of New York Harbor. This dumping in water depths of 2,500 m (8,000 ft) caused local increases in pollution and restructured the deep-sea community of organisms. During the course of six years, studies showed that a significant fraction of the sludge material dumped by barges reached the ocean bottom slightly west of the area where it was discharged, and that it had measurable effects on the metabolism, diet, and composition of organisms that lived there. This was contrary to expectations that the sludge might not reach the bottom, but would instead be diluted and swept away.

NURP/MAB

A trawl sample at the 106-mile dumpsite shows the diversity of life at 2,500 m.

Sludge disposal at the 106-Mile Dumpsite was curtailed in July 1992. “This provided additional opportunities to examine the long-term dispersal and effects of waste material in the deep-sea environment,” Bothner said. While the effects of sludge dumping appeared to be abating in the vicinity of the dumpsite, an additional chapter to the story of the 106-Mile Site still remains to be written. Levels of silver appeared to be on the increase 50 nautical miles south of the dumpsite, as did the densities of sediment-dwelling organisms. The recovery at the dumpsite coincided with changes in habitats further downstream as resuspended materials were transported to the south of the dumpsite.



Ocean Biodiversity

Once considered a barren desert, the deep sea now reveals its richness. From the hydrothermal vents of the mid-ocean ridges to the cold seeps in the Gulf of Mexico, scientists are discovering unique life. Here, in total darkness fed by chemicals in the vent fluids, are virtually undescribed communities—perhaps the precursors of life on Earth. Called extremophiles for their ability to flourish in the world's most extreme environments, microbes and animals from the deep sea can be tapped for potential commercial and biomedical applications.

In this chapter of the report, explore with NURP researchers the unique chemistry and organisms of hydrothermal vents, cold seeps, and hot spots. Extreme environments are now the focus of scientific study because they're a novel source of chemicals to oceans and lakes, and a unique source of organisms totally isolated from all other strands of evolution.

Spider crabs around vent sites on Juan de Fuca Ridge.

Hot Vents

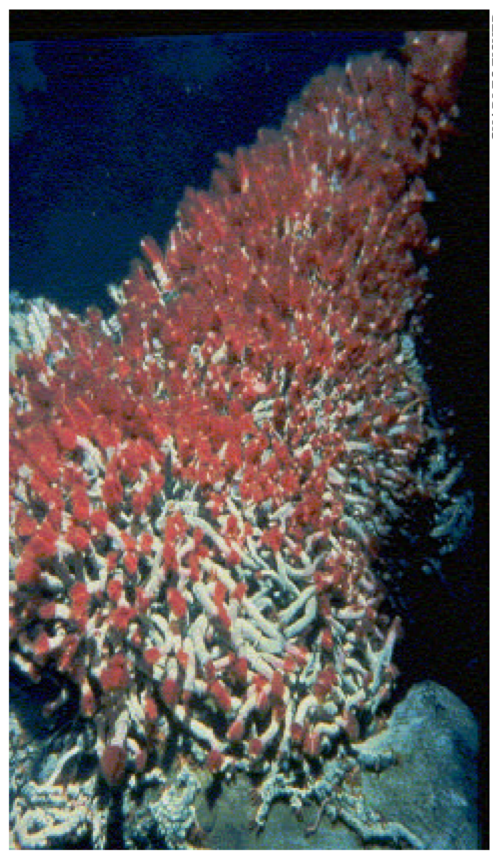
The existence of life in the ocean abyss was a recent discovery that revolutionized scientific theory in the 20th century. Likened to the "hideous sights of ugly death" by oceanographer Matthew Fontaine Maury a century ago, the deep ocean bottom was largely ignored. But in the past two decades, undersea technology has enabled marine scientists to explore the seafloor in detail previously impossible. Across the globe from the hydrothermal vents of the Mid-Atlantic Ridge to the hot springs of Yellowstone Lake, unique ecosystems are being discovered in aquatic environments previously considered barren. Here, in total darkness fed by chemicals in the vent fluids, live virtually undescribed communities—may be the precursors of life on Earth.

Undersea researchers only recently began to explore the single largest mountain range on Earth called the mid-ocean ridge, covering almost 23 percent of the planet's surface, with cliff walls that rival the Grand Canyon. The ridge is a zone where the tectonic plates that form the Earth's surface are spreading apart and magma from the Earth's interior is rising to create new seafloor. As the plates shift, continents are being carried on a pliable upper layer of the Earth's mantle, like boxes on a conveyer belt. Seawater percolates down the quake-fractured ocean crust closer to the molten magma in the Earth's interior. The heated seawater becomes buoyant and rises through cracks to the surface as hydrothermal vents. The venting of submarine volcanoes creates black smokers, named for the sulphide and oxide mineral particles billowing upward above the chimneys created by the venting.

These vents are now the focus of scientific study by marine geophysicists, geochemists and biologists funded by NURP. Vents are a novel source of chemicals to the oceans and a unique source of organisms totally isolated from all other strands of evolution. "As well as forming mineral deposits, which are analogs of deposits mined on land and potential resources for the future," said NURP researcher Peter Rona, a marine geophysicist with Rutgers University, "the global ridge system is a safety valve for the Earth as a whole in terms of releasing and trapping heat and chemicals to keep the balance of the planet."

Hydrothermal vents were first discovered in 1977 on an expedition to the Galapagos Rift, which lies between the East Pacific Rise and the South American mainland. An expedition led by researchers at Oregon State University in the submersible *Alvin* carried two scientists and a pilot to the 2,500 m (8,000 ft) deep rift. The research team was looking for hot springs because their heat budget and chemical signals indicated that there should be warm water flowing out of the crust. In addition to finding the vents, the scientists found abundant animal communities. The most dominant creatures were giant tube worms, dinner plate-sized clams, and mussels in striking numbers. What puzzled the scientists was that these life forms existed, especially in such biomass, in the deep sea devoid of the light and the nutrients thought necessary for life.

Even more astonishing to biologists was that the giant tube worms they found lacked mouths and digestive systems. How could such a big organism exist in thickets without taking in food? What the researchers



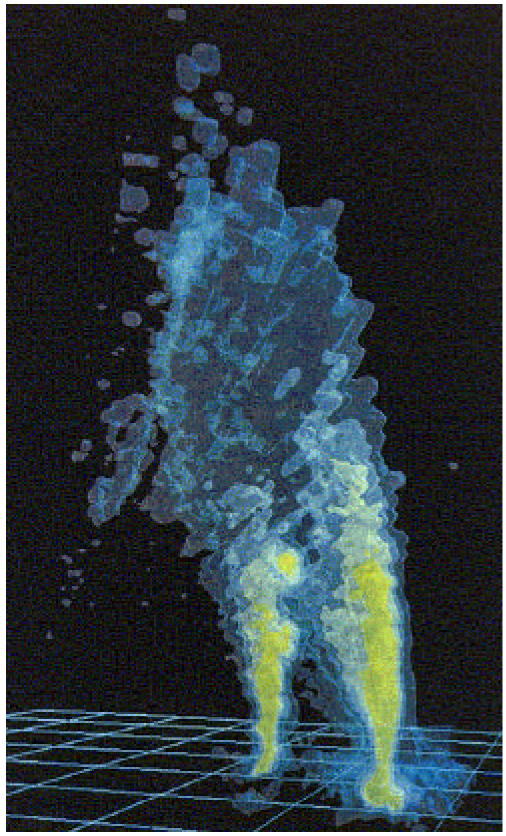
CHARLES FISHER

Tube worms feeding in foreground of black smoker, Juan de Fuca Ridge.

eventually found was that hydrothermal vent animals get their food from inorganic materials contained in the vent fluids and gases. In particular, hydrogen sulfide, a chemical that is toxic to most forms of life, is converted by sulfide-oxidizing bacteria living within the vent animals into organic matter that the animals can consume. Much like plants use light (photosynthesis) to convert water and carbon dioxide into sugar, vent animals use hydrogen sulfide in a process known as chemosynthesis.

In subsequent expeditions, researchers found chemosynthetic communities at ocean floor hot springs along the spreading centers of the world's plates. So many new fauna are being discovered that many new names and classifications for the animals have to be created. Despite the similarities among vent communities, there is also great biodiversity in the vent fauna around the globe. For example, no giant tube worms have been found in hydrothermal fields in the North Atlantic Ocean. This leads to the conclusion that some of these biological communities have evolved independently for perhaps millions of years. Another mystery is how hydrothermal organisms can survive through the generations. Vent fields and chimneys remain active for a finite period ranging from years to centuries, so for any one species to survive they must have the ability to migrate to another vent site. How this works is still a mystery because the mode of reproduction and the mechanism for the distribution of vent animals is unknown. Since the vent communities are stationary as adults, the species must produce planktonic larvae capable of migrating along the ridge axes to colonize new vent fields.

A recent NURP-funded study aims to determine how vent animals reproduce. Cindy Lee Van Dover, a biological oceanographer currently at the College of William and Mary, and Paul Tyler, a deep sea reproductive biologist at the Southampton Oceanography Center, collected and sampled hundreds of vent animals in 1995. Even at such depths, it has been proposed that vent animals reproduce in response to some lunar tidal cycle, the same phenomenon that bivalves respond to in shallow water. Van Dover, a former Alvin pilot, describes her voyages to hydrothermal vents in a book called *The Octopus's Garden*.


PETER RONA

A three-dimensional acoustic image of two hydrothermal plumes discharging from adjacent black smoker vents on the East Pacific rise.

The effects of hydrothermal activity on ocean chemistry go well beyond the immediate vicinity of vent sites. A three dimensional acoustic imaging system, mounted onto the Navy submersible *Turtle* on NURP-supported dives at 2,600 m (8,530 ft) on the East Pacific Rise, helped Rona capture just how far the plumes of two black smoker vents traveled in the water column. The image, obtained using sonar, showed the plume of shooting mineral particles more than 40 m (130 ft) into the water column. Physical oceanography models show how mineral particles and animals from hydrothermal vents might be pulled away from their original sources along the world's mid-ocean axes and distributed.

Scattered around the Earth under continents and oceans, in the center of plates, and at midocean ridges are specific areas of isolated volcanic activity known as hot spots. Yellowstone Lake, the largest high altitude lake in North America, is one of the most tectonically active regions in the world. The lake lies above magma chambers that are the source of heat for geysers, hot springs, fumaroles, and mud pots that typify the park. James Maki, a microbial ecologist at Marquette University and colleagues

Charles Remsen, Val Klump, and Russell Cuhel from the University of Wisconsin-Milwaukee, are currently studying hydrothermal activity in the lake and its influence on the distribution of organisms. These researchers use a remotely operated vehicle (ROV) rigged with cameras and sampling devices to view and collect fluids from vents 100 m (328 ft) deep. The hydrothermal springs, which are 112° C and hot enough to boil an egg, create a range of thermal and chemical conditions that promote the growth of a wide variety of bacteria and microorganisms. Some of these organisms resemble the sulfide-oxidizing bacteria found near mid-ocean hydrothermal vents. However, in contrast to the deep-sea vents, larger vent animals like tube worms and clams are not associated with the hydrothermal activity in Yellowstone Lake.

Maki was also able to isolate and characterize a new genus of sulfate-reducing bacterium. "The isolation and characterization of this bacterium underscores the importance of hydrothermal environments of Yellowstone Lake as a source of novel microorganisms," Maki said. This group's research points to a whole diverse community of microorganisms that are still unknown, and whose enzymes may have some biotechnological use. The vents appear to play a very important role in the lake basin as a whole. Cuhel has observed that chemosynthetic activity appears to be a more important contributor to primary production throughout the lake at certain times of the year than photosynthesis, and could be an important underpinning of the entire food chain. The lake is one of the great reservoirs for cutthroat trout in North America, and trout are a very important food source for eagle, osprey, and bear. Researchers hypothesize that particulate material spewed up by lake geysers, may fuel the food chain that help support the trout.

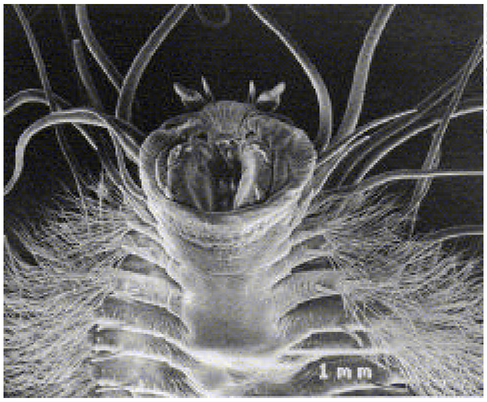
Cold Seeps

Oceanographer Ian MacDonald of Texas A&M University and marine biologist Charles Fisher of Pennsylvania State University were surprised to find similar animals using chemosynthesis to feed off the hydrocarbon gas seeps on the seafloor in the Gulf of Mexico. They've spent ten years studying the tube worms and mussels that colonize over hundreds of square miles at depths down to 3,600 m (11,800 ft) in the Gulf of Mexico with NURP support. The seep community attracts other animals including snails, eels, crabs, and fish, raising questions of how far the food web extends in the deep ocean and how it affects the health of the ocean. Then by accident came a remarkable discovery in 1997. On a planned mission to continue studies of oil seep communities, Fisher and MacDonald discovered a new species of worm living within mounds of frozen natural gas on the sunless floor of the ocean. MacDonald had taken photographs of the worms before, but neither he nor Fisher expected to find a huge colony of the worms living on and in the gas hydrates.

While scientists have found extremophiles—organisms named for their capacity to survive, even fluorish, in the ocean's most extreme freezing, scalding, and acidic waters—most have been microbes, not animals. Dubbed the ice worm until a scientific name can be given to the new species, these pink-colored worms that look like two-inch long centipedes are a variety of the common aquatic worms known as polychaetes. What makes the iceworms such interesting subjects is that these animals can survive in such potentially toxic environments.

Recently, gas hydrates worldwide have generated a great deal of interest. The hydrates are lattices of ice, inside of which are trapped molecules of methane, that form under extreme pressure trapping the methane gas. Huge reserves of natural gas methane

A reservoir greater than all the retractable reserves of oil are bound in gas hydrates.



CHARLES FISHER

A closeup of iceworm.

are bound in these gas hydrates, a reservoir greater than all the retractable reserves of oil and as much as two to three times the carbon that exists in all the living biosphere, MacDonald said. "There's a wonderful irony in this discovery," MacDonald said. "While we're considering the impact of human activity in the deep sea related to oil production, we find a natural presence (iceworms) already at the resource we're beginning to exploit. Gas hydrates like hydrocarbon seeps are ecosystem shaping processes." These hydrates may enable hydrocarbon seep communities to survive. As gas hydrates are formed, blocking and releasing hydrocarbon gas and dispersing oil onto sediments like a drape, broad communities of fauna exist. The tube worms that establish themselves in an area of several hundreds of meters wide, are receiving a steady supply of gas through the hydrate, MacDonald said.

Scientists also theorize that by consuming methane, a greenhouse gas, these vent animals may be contributing to the health of the planet. "The question that comes to mind is what's going to happen if bottom water temperatures increase as a result of global warming," MacDonald said. "The seep communities are intricately linked to the system extracting gases through the hydrate and changing the temperature flux of the sediment layer. There's a whole biological interaction, we just have to understand it."

Why The Interest?

It might sound far fetched, but researchers are turning to places like the boiling waters of Yellowstone Lake or inside the frozen layers of Antarctic ice to find extremophile microbes that might be used in applications ranging from the production of sweeteners and stone washed jeans to diagnostic tests for infectious and genetic diseases. Extremophiles have unique enzymes, called "extremozymes," which enable them to function in such forbidding environments. The biomedical field and other industries worldwide spent more than $2.5 billion last year looking for ways to use extremozymes. Since extremozymes tolerate extreme temperatures, they have an edge over other enzymes. Heat loving microbes like those found at mid-ocean ridges are used to increase the efficiency of "DNA fingerprinting" to stabilize volatile food flavorings, improve the uptake of medicines by the body, and mask unpleasant odors.

Extremophiles like those found within Antarctic sea water are also of interest to manufacturers who need their enzymes to make products like fragrances and laundry detergents that last longer when kept in colder conditions. While chemicals from land-based plants and microbial fermentation are on the decline, scientists have barely scratched the surface of the seas's molecular potential. One marine microbe that recently proved to be a potent killer of cancer cells, as well as an active agent against tissue inflammation, was isolated from the surface of a jellyfish. Blue-green algae are being studied to prevent strokes or heart attacks. These are just a few examples of how compounds from the sea can be tapped for human use.

Tacoma, Washington.

Arctic seal.

Predicting Environmental Change

As the debate intensifies over possible man-made influence on climate, scientists are working to discover and understand links between the atmosphere and the ocean, and natural climate variability across the globe. Global climate change is a recurring theme throughout Earth's history. The presence of continental ice sheets and concurrent drops in sea level have left spectacular evidence of past climate cycling. Follow NURP researchers on a journey to lost continents beneath the ocean to learn about how past climate history holds clues about potential climate change in our future.

An important part of our atmosphere, carbon dioxide, contributes significantly as a greenhouse gas that can effect global climate change. To narrow the uncertainties about the global effects of carbon dioxide, and to improve our understanding of the trends and forcing of greenhouse gases, NURP researchers have focused on the ocean's exchange of carbon dioxide with the atmosphere, and the ocean's vast reservoir of carbon. Until it is fully understood how carbon is regulated by biological, chemical, and physical processes in the ocean, the many roles of atmospheric carbon dioxide cannot be accurately understood.

In this chapter, we learn how a NURP researcher succeeded in measuring the cycling of carbon dioxide in the coastal ocean. We also learn how submerged islands, coral reefs, and underwater volcanos found in the oceans of North America offer important clues about climate history and possible triggers that cause climate change.

Recorders of Climate History

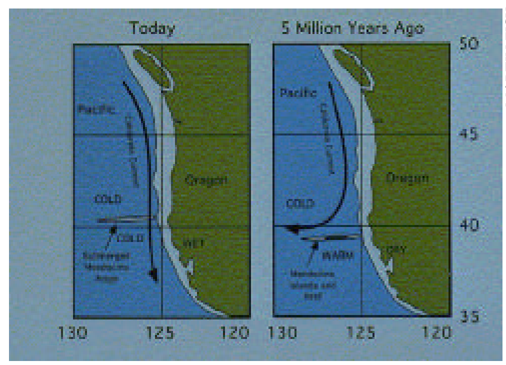
As our knowledge builds regarding man-made influences on climate, scientists are working to discover and understand links between the atmosphere and the ocean, and natural climate variability across the globe. Submerged islands, coral reefs, shorelines, and underwater volcanos found in the oceans offer important clues about climate history and possible triggers that cause climate change. Understanding the link between the atmosphere and ocean is a key goal of climate research funded by NURP. Just as the growth rings of a tree tell its age, scientific evidence for climate change is contained in the physical and chemical properties of the sea floor.

Long-term changes in climate, those that occurred millions of years ago, can come from slow changes in the configuration of the ocean basins and continents. Continental drift, also known as plate tectonics, has moved India and Southern Africa from regions where they were ice covered to their present tropical and temperate conditions. Ocean currents such as the Gulf Stream also control the climate and are controlled by the motion of the Earth's surface. Plate tectonics can block and divert these currents. A recent NURP-funded study found that an undersea ridge off northern California rose well above sea level some five to seven million years ago. This ridge blocked the cold, southward flowing California current and changed the climate in the Pacific northwest. This finding is important because it will help scientists understand how the currents in the Pacific historically affected the climate of North America.

Mendocino Ridge, a major submerged mountain range along one of the Earth's largest fracture zones some 1,200 m (4,000 ft) below sea level, was once a string of islands off the coast of San Francisco. The ridge was uplifted through the collision of the Pacific and Gorda plates some five millions years ago, then subsided through sheer weight. Thirty-seven years ago, oceanographer Dale Krause at the Scripps Institution of Oceanography theorized that the ridge had been at sea level, but it wasn't until 1995 that he got proof. Diving in U.S. Navy submersibles *Sea Cliff* and *Turtle* and using a remotely operated vehicle, two Oregon State University geologists Martin Fisk and Robert Duncan observed smooth boulders at the crest of the Mendocino Ridge similar to those found on rocky beaches today.

The California current that comes out of the Gulf of Alaska delivering cold water down the coast of California would have been blocked by the newly discovered island chain, and warm water from the south would have drifted north along the coast. "This could have set up circulation systems that would have changed climate," Fisk said.

Did the submerged island chain trigger the advent of the ice age that started two million years ago? "Something triggers these long episodes of ice," Fisk said. "If we can figure out what happened to the climate of California and Oregon when the current was blocked, we should be able to better understand what effects our climate today." Better models of how the Earth's plates moved and their effect on climate in the past will help scientists estimate the effects of other recent changes like global warming, he said.



MARTIN FISK

Maps of the California Current today and in the past. The emergence of the Mendocino Islands five million years ago could have diverted the California Current to the west. This would have allowed warm water to drift north to where San Francisco is today. Northern California is probably wetter now than it was then.

Coral reefs are also exceptional recorders of climate history. Despite their fragile beauty they have managed to survive for the last 500 million years of Earth's history, and kept a diary of changes along the way. NURP-funded scientists are unfolding the secrets kept by ancient coral reefs and lost shorelines that laid the foundation for the distribution of reefs in South Florida today. They are studying the reefs to learn about past sea level and climate, as well as to learn what makes corals grow or die.

About 125,000 years ago at sites now occupied by Miami and Key West, huge sand bars were created by strong tidal currents.

Hurricane damage.

The two cities now lie at either end of an ancient coral reef established on top of the sand bar which we now know as the Florida Keys. Where bait and tackle shops, motels, and dive shops dot the scenic road through the Keys, a vast living reef once flourished. "Sea level was 20 feet higher than it is now," said Eugene Shinn, project chief of the U.S. Geological Survey (USGS) in St. Petersburg, Fla., "and a coral-studded shelf extended east five miles to the edge of the Gulf Stream." Shinn has studied coral rocks for the past 35 years to gain information about what the environment was like in the past, as a way to predict how it might respond in the future. His work on coral reefs is extensive. Underwater excavations, rock corings, and acoustic surveys of rock outcroppings and sediments, have enabled the geologist to build a picture of how reefs were distributed in Florida during the ice age known as the Pleistocene Epoch. The carbon-14 method allows him to date peat from underwater, in swamps, beneath reefs, and under reef sands. Since peat only forms above sea level, scientists can use it as a marker of sea level history in the last 10,000 years. Growth bands in the skeleton of corals also preserve a record of seawater temperature and salinity during this period.

Why reefs exist in some regions of South Florida today and not in others is still a subject of ongoing research. After the last ice age flooding, reefs began to grow on topographic highs in some areas of the region, but not in others. In a process called backstepping, geologists observed how reefs grew upward and landward away from the sea in response to rising sea level. Those that couldn't keep up with sea level rise died, Shinn said.

"Corals, which have survived for the last 500 million years of Earth's history, will certainly live through the vagaries of sea level oscillations well into the future," Shinn said. Increasing population and coastal development, however, may pose a greater, added threat to these ancient ecosystems. Marine sanctuaries that afford reefs protection will enhance their survival, he said.

Undoubtedly, alternating periods of freezing and thawing had a significant effect on the ocean and the continents themselves. Sediment cores taken off Wrightsville Beach, a barrier island in the southeastern part of North Carolina, helped NURP researchers reconstruct a picture of how climate shaped the landscape since the height of the last glacial period. Geologists Orrin Pilkey and Robert Thieler of Duke University found the remnants of a 9,000-year-old barrier island lagoon system located 8 km (4.9 mi) offshore. At the peak of the glacial period, coastal plains near the edge of the continental shelf were fronted by lines of sand dunes. Rising sea level caused the ocean to break through the dunes and form a lagoon, a long, shallow body of seawater isolated from the ocean. The high lines of coastal dunes became islands. As sea level continued to rise, wave action caused the islands and lagoons to migrate landward running over old rivers and estuarine deposits from previous lower sea levels.

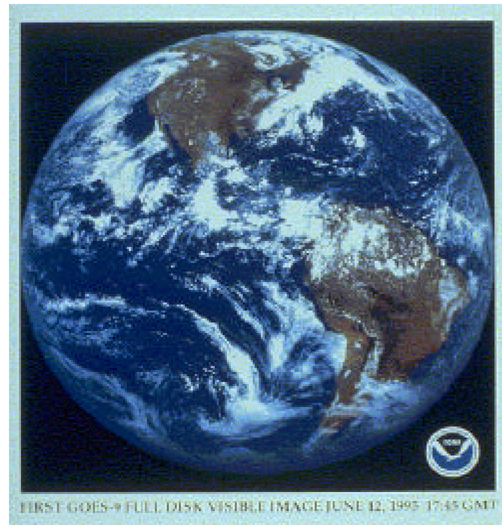
Over the last several thousand years many barrier islands have grown by accumulating sediment from the continental shelf. Today, Wrightsville Beach and many other islands are eroding along both their lagoon and ocean shorelines containing the natural pieces documented by those researchers who suspect this may be a result of an increased rate of sea level rise.

In the future, if the ocean were to expand and the polar ice caps were to melt, sea level could rise driving the coast inland even further. The impacts to coastal cities (where one-third of the world's people live), deltas, and wetlands would be astronomical.

"The big question now," said Thieler, "is when and how fast future climate change will be."

Oceans' Role in Climate Change

Natural greenhouse gases—from volcanic processes to the decay and burning of organic matter to biological respiration—keep the Earth warm. What prevents the planet from overheating is the removal of these gases by plant photosynthesis and seawater absorption. But now it appears carbon dioxide primarily from combustion of fossil fuels may be produced at a rate faster than it can be assimilated by biotic respiration or the ocean. To make matters worse, forests and jungles are clear-cut and their absorption lost. Global temperature is on the increase since the last ice age. However, scientists are still uncertain about the magnitude of human-induced component of global warming. Unpredictable natural processes like the fluctuation of energy output from the sun or the eruption of volcanos like Mt. Pinatubo in the Philippines that release dust and gas (for example, carbon dioxide) into the atmosphere can greatly influence temperature. The submarine volcano, Loihi, also introduces natural gases and particles into the undersea environment. Loihi, which is



NOAA

First GOES-9 image of clouds over the Americas.

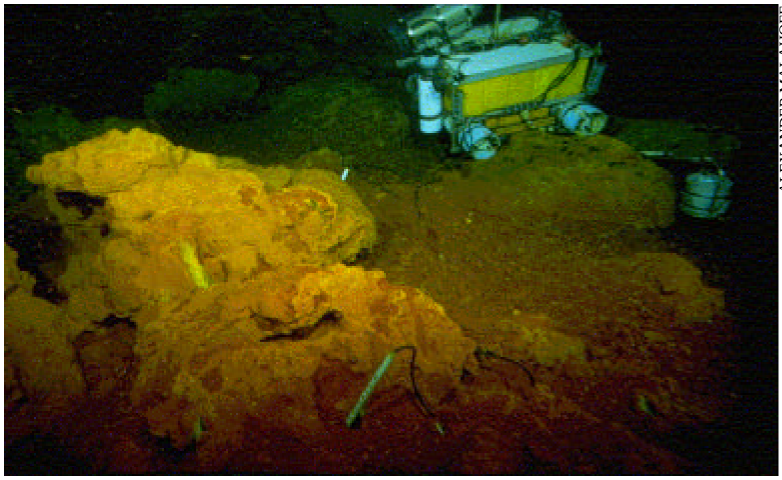
only one of the hundreds of thousands of submarine volcanoes, is part of an emerging link of islands along the Pacific Plate and has been under intense study since two years ago when the largest set of earthquakes ever recorded shook the seamount.

A series of dives in the submersible vehicle *Pisces V* led by NURP scientist Alexander Malahoff, director of NURP's Hawaii and Western Pacific Undersea Research laboratory, enabled scientists to observe an island being formed and the chemical processes that occur during such an event.

Using Loihi as a natural laboratory for continued studies will be important in understanding the role that hydrothermal vents play in the global carbon system. Along with atmospheric influences, carbon cycling in the deep ocean is necessary for modeling and predicting global chemical and climactic change in the future, said microbiologist James Cowen of the University of Hawaii. What is the total export of carbon from hot spots into the atmosphere? Do these submarine volcanos have a major impact on global warming? If most of the carbon dioxide released from the Earth's mantle did not get bound up in sediments and unrespired organic carbon, the Earth's atmosphere would be similar to that of Venus, where carbon dioxide constitutes 95 percent of the atmosphere. Clearly, the ocean is a major reservoir of carbon, but how is it responding relative to increases in carbon dioxide from human activities in the last 200 years? This is one of the most important questions of chemical oceanography today, NURP researchers said.

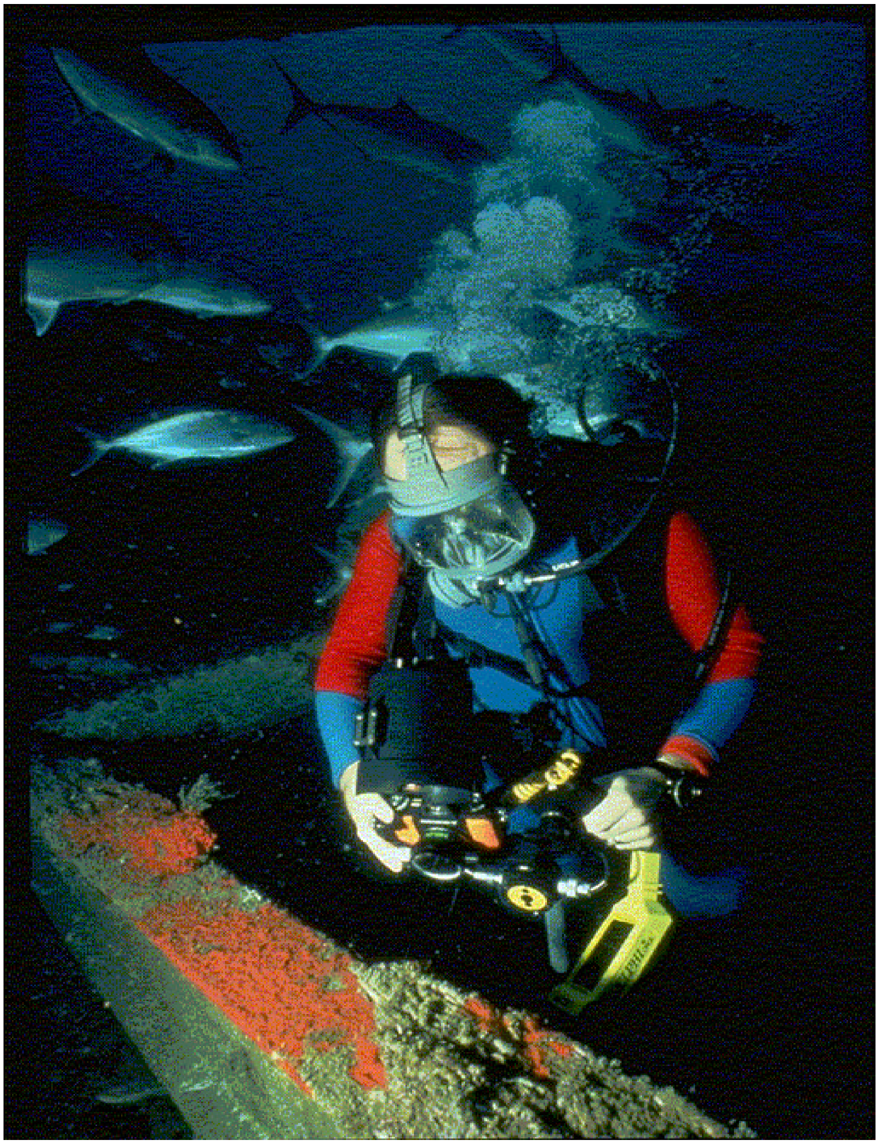
Until it is fully understood how carbon is regulated by biological, chemical, and physical processes in the ocean, atmospheric carbon dioxide cannot be accurately modeled. Present evidence suggests that the ocean is a major sink for carbon dioxide from anthropogenic sources.

Modeling the distribution of carbon dioxide in the coastal ocean is more difficult than the deep sea because of its variability including huge seasonal shifts in the biotic productivity, as well as an immediate chemical exchange of carbon between the sea floor and the surface water that doesn't exist in the open ocean. To measure rates of oxygen consumption and carbon dioxide production by microorganisms living in sediments on the continental shelf of New Jersey, chemical oceanographer Clare Reimers of Rutgers University used *in-situ* sensors deployed from a NURP remotely operated vehicle. "What we're finding to my surprise," said Reimers, "is these sands that have hardly any organic matter in them at all are still becoming anoxic usually within two to five milliliters below the interface." This implies that fresh reactive organic materials (remains of phytoplankton) are rapidly being degraded by microorganisms consuming all the oxygen.


ALEXANDER MALAHOFF

Ocean observatory at Pele's Vents.

With two years' worth of data, Reimers observed concentrations of carbon dioxide in the water at its highest (and oxygen at its lowest) in the summer and fall months when the ocean acts as a source of carbon dioxide to the atmosphere. In winter months, the opposite is true. Carbon dioxide levels are lower than the atmosphere and the coastal ocean acts as a sink. "Overall, it appears that the coastal ocean is not acting as a major source or sink for atmospheric carbon dioxide," Reimers said. "It's an important piece of information for global modelers, because it tells them that if all coastal systems acted like this one, they could ignore coastal regions in their global carbon dioxide balances."



Safe Diving

The Outer Continental Shelf Lands Act of 1978 authorized NOAA to perform studies to improve the safety and efficiency of all divers—scientific, commercial, and recreational. NURP carries out this mandate for NOAA through development and support of innovative dive technologies and techniques. More than 600 scientists and students each year receive advanced diver training and field support for their research. In addition, program outreach includes notable public service efforts such as the *NOAA Diving Manual* (NOAA's most popular publication) and the Diver Alert Network (a safety net for divers around the world).

This chapter discusses ways NURP increases the safety and productivity of scientific divers.

Scientific Diver Training and Technology

Decompression sickness (DCS or “the bends”) is the most common diving ailment due to pressure. While diving, gas builds up in the diver’s tissues, particularly the inert gas nitrogen which makes up 78 percent of the air we breathe. If the diver ascends and reduces the pressure too quickly, these gases may come out of solution too fast in the blood stream and form bubbles, much like a soda bottle that is opened too quickly. Early symptoms may include nausea, dizziness, tingling or numbing sensation in extremities, and joint pains (thus the name the bends). Primary treatment, called recompression, simply involves getting the diver back under pressure and bringing the diver up slowly. Another problem when diving below 30 m (98 ft) on air is nitrogen narcosis, or “rapture of the deep,” characterized by disorientation and confusion which can be dangerous when diving deep. One way to reduce the risk of DCS and nitrogen narcosis is to reduce the amount of nitrogen in the diver’s air by replacing it with oxygen. The resulting breathing mixture is called nitrox. The benefits are obvious. Besides a clearer head, a diver using a nitrox mix with 32 percent oxygen versus the 20 percent in ambient air can stay down twice as long at 40 m (131 ft).

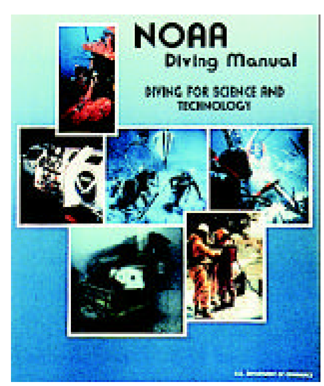
Nitrox has been used for decades by industry and the military to increase bottom time. Its acceptance by the recreational and scientific dive communities was delayed due to a lack of widely accepted dive tables and the technical problems of preparing special mixes of breathing gas. This problem was addressed in the 1979 edition of the *NOAA Diving Manual*, published by NURP, which included techniques and tables for the safe use of nitrox. “There’s no special dive equipment required for using this gas mixture,” said Gene Smith, NURP’s program director for Diving Safety and Physiology. “That’s the main appeal of nitrox.” However, there are safe practices for the use and mixing of nitrox that go beyond the basic training received by most divers, Smith advised. Some practices of obtaining nitrox must be avoided, like adding 100 percent oxygen from a welding set to an old air cylinder possibly contaminated with hydrocarbons (an explosive combination). The next edition of the *NOAA Diving Manual* will include improved tables for more mixtures of nitrox improved through NURP-funded studies and useful guidelines and references for the preparation and application of mixed gases in diving.

NURP’s regional center at the University of North Carolina at Wilmington provides scientists with mixed gas diving support and training. Between 1995 and 1997, the southeast center supported 5,000 nitrox dives with a flawless safety record, said David Dinsmore, director of NOAA’s Diving Program, who previously served as operations director of the North Carolina center. In 1996, Mark Hay, a benthic ecologist at the University of North Carolina at Chapel Hill and his graduate students were led by NURP on more than 400 dives to “live bottom” reefs on the continental shelf off North Carolina, critical habitats for many species of commercial fish. “We simply couldn’t justify the time and expense using scuba,” said Hay.

Future development efforts will increase the depths and range of environments scientists can study. Too much oxygen is toxic. Gas mixtures using helium can further

NURP/UNCW

Pool training prior to *Aquarius* saturation mission.



NURP's Active Dive Record 1995-1997

	Subs	ROVs	SCUBA	Participants
Total	796	1132	20945	2618

NURP actively provides undersea technologies for scientific research including submersibles, ROVs (Remotely Operated Vehicles) and SCUBA (Self-Contained Underwater Breathing Apparatus).

increase the productivity of divers without "rapture of the deep." The key to all program efforts is to increase the productivity of scientific diving without sacrificing safety. "Scientists now know that they can more safely and efficiently achieve their dive plans with nitrox, " Smith said. " NURP gave NOAA the ability to acquire these advanced commercial and military diving techniques."

Diving Tools

Diving is made safer and more efficient with tools developed by NURP. The fourth edition of the *NOAA Diving Manual* is due out this fall. The new diving manual has been expanded and revised with instructions, recommendations, and general guidance for performing a diversity of tasks underwater. The Manual contains valuable information on topics such as the latest diving equipment, working dive procedures, diving under special conditions, hazardous aquatic animals, emergency medial care, and tables for the use of mixed gas. While the latest *NOAA Diving Manual* is primarily directed toward members of NOAA and the scientific diving community, recreational divers will also find useful information on topics like the history of diving to diving physiology. The manual pools together the contributions of more than 50 authorities including scientists, doctors, commercial and recreational divers, equipment manufacturers, and educators who wish to share their knowledge and experiences of diving.

Another useful tool for divers is the *DiveTracker*™ product line, developed by Desert Star Systems of California and substantially funded by NURP-sponsored Small Business Innovation Research (SBIR) grants. This system combines precision underwater navigation, observation recording and e-mail style wireless communication in a calculator size underwater computer. What started out as a system for divers to acquire, store, and transmit environmental data from the sea floor, has been modified for a wide range of tasks. *DiveTracker*™ has guided ROVs through refinery fuel storage tanks, docked AUVs at underwater fueling and data exchange stations, monitored U.S. Army Ranger recruits for signs of hypothermia, and aided the U.S. Navy in the recovery of torpedoes after test firings. *DiveTracker*™ will be used by NURP science divers on research missions at the *Aquarius 2000* undersea habitat.

Public Service

These days, you will not find a diver with any experience who is not familiar with DAN—the Diver's Alert Network. DAN was established in 1980 at Duke University Medical Center with support from NURP and the National Institutes of Health to provide a medical advisory service for divers. In case of dive injuries, divers or physicians can call the DAN 24 hr. emergency hot-line and talk to a dive physician. If needed the physician will work with a DAN Regional Coordinator to arrange referral and transport to an appropriate medical facility. For a modest fee a diver can join DAN and purchase diving medical insurance that covers all treatment costs including helicopter transport if needed. In 1998, DAN estimated they have taken more than 140,000 calls for diving medical assistance, and annually advise in the treatment of up to 500 divers worldwide. DAN programs are described at their world-wide-web site, http://www.dan.ycg.org.

The Diver's Alert Network logo.

NURP/UCAP

The *Johnson-Sea-Link* on R/V *Seward Johnson*.

Tools for Undersea Research

Understanding the ocean is one of our most important challenges today, thus the development of sensing, sampling, and observing systems to support that mission is essential.

The National Undersea Research Program (NURP) is the nation's scientific research program that specializes in providing access to advanced undersea diving and observation technologies. The tools NURP scientists use to explore beneath the sea range from research submersibles, remotely operated vehicles (ROVs), and autonomous underwater vehicles (AUVs) to underwater laboratories, sea floor observatories, and mixed gas diving.

NURP's undersea technologies are used by researchers to get to the sea floor where they can observe, describe, and ultimately explain the phenomena of the oceans and life within it. The oceans are the most complex, challenging and harsh environments on Earth, and to access them requires technology.

Ocean science and exploration play an important role in the responsible stewardship of the environment of our planet. "What submersibles allow us to understand is the full complexities of the ecosystem," said oceanographer Ian MacDonald of Texas A&M University. "You can't map the sea floor and its associated geology and ecology unless you get down there and observe it. Not seeing the complexity of the ocean is like not seeing the trees in the forest."

The national needs for undersea research and NURP's technological capabilities are characterized in this chapter.

The National Undersea Research Program—In Perspective

One year after the National Oceanic and Atmospheric Administration (NOAA) was created in 1971, the Manned Undersea Science and Technology (MUS&T) office began to provide undersea technology primarily for NOAA investigators. In 1979, the National Research Council (NRC) reviewed MUS&T and endorsed the idea for formation of a National Underwater Laboratory System, which later became The National Undersea Research Program (NURP). Ocean resources and environmental problems vary across regions and different technologies are needed, thus the NRC panel supported the regional laboratory system. The program maintains a small headquarters office based at NOAA's Silver Spring, MD, location, and regional undersea research centers. The host institutions provide permanent facilities and infrastructure, so administrative costs are lower. The close ties NURP regional centers have to the regional science community facilitates identification of priority environmental issues and use of appropriate technologies for research projects.

NURP Technologies

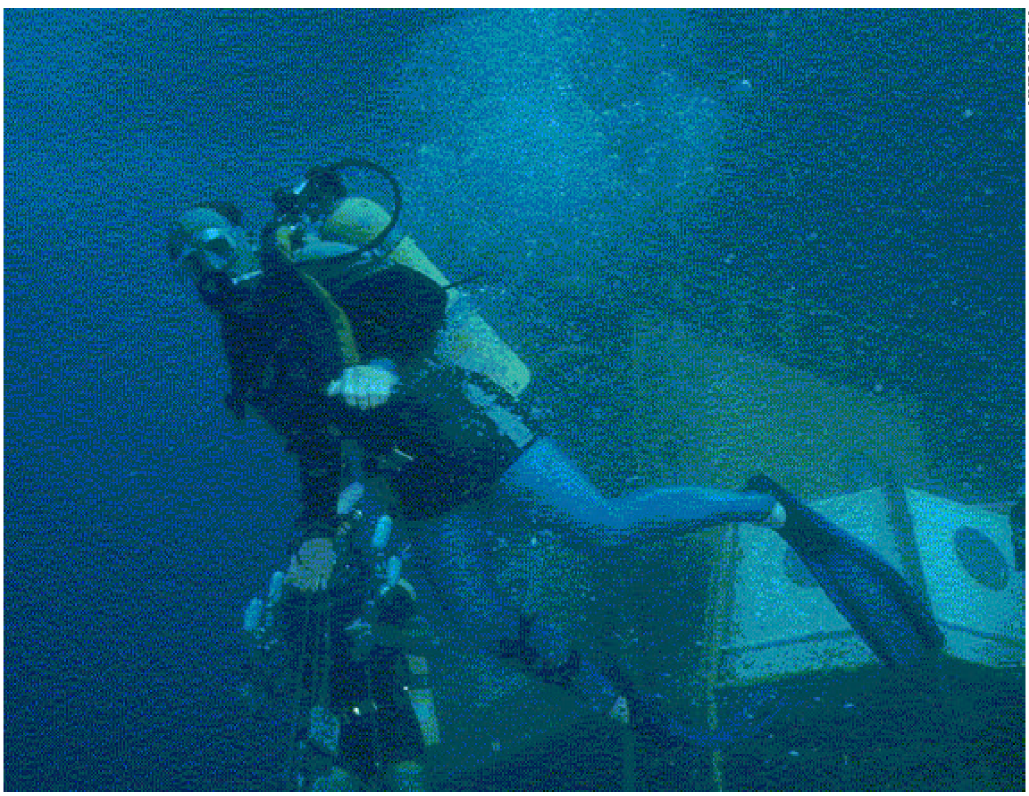
In 1980, the National Research Council (NRC) recognized the need to facilitate access by the nation's science community to undersea procedures and equipment. A more recent NRC report (1996) reinforces the continuing need for development of new, more advanced capabilities.

NURP serves the science community by making undersea technologies, which NURP either owns or leases, available for scientific research.

Advanced Scientific Diving

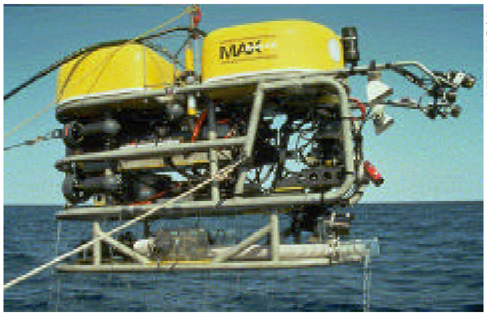
In shallow water, the most effective way to study the seas is to place humans directly underwater. Although strides have been made to make deeper diving possible, there are still severe restrictions on the depth and length of time divers can spend underwater. Research on undersea ecosystems often requires diving to depths beyond 40 m (131ft)—work that can't be done with conventional scuba diving equipment.

Using oxygen enriched air (nitrox), divers are able to extend their bottom time. NURP provides scientists with both nitrox equipment



NURP/UNCW

Dr. Stephen Wing departs *Aquarius* for a reef dive to examine how internal waves affect reefs.



NURP/UCAP

The ROV *Kraken.*

A deployment of the *Odyssey* AUV in Antarctica.

and personnel to carry out their missions. In 1997, the program helped scientists conduct more than 2,000 nitrox dives with a flawless safety record.

Divers working from surface vessels are limited by factors such as weather, gas supply, and decompression sickness. The ability to live and work beneath the waves is provided through saturation diving and the *Aquarius* undersea laboratory, the only undersea habitat in the world devoted to science. The habitat, owned and operated by NURP, is located in 20m (65 ft) of water at the base of a coral reef within the Florida Keys National Marine Sanctuary—an ideal site for studying the health of sensitive coastal ecosystems. The habitat accommodates four scientists and two technicians for missions averaging ten days. The *Aquarius* program successfully completed 21 missions over a 32-month period between 1993 and 1996. It was recently upgraded with modern communication systems to enhance continued operations for the next five years. Achievements include description of the damaging effects of ultraviolet light on coral reefs; improved understanding of coral feeding biology; fossil studies to better understand present-day changes to coral reefs; and water quality studies to evaluate pollution sources and impacts.

Robotic Vehicles

NURP operates undersea robots or remotely operated vehicles (ROVs) that can be deployed from ships of opportunity. Access to a variety of ROVs is provided—some leased, some owned by the program. NURP's ROVs have worked from the tropics to the poles.

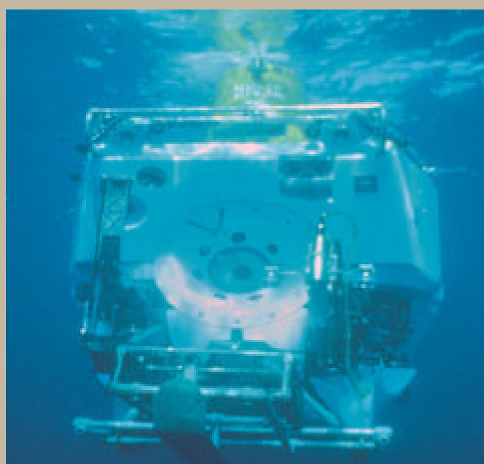
Autonomous Underwater Vehicles (AUVs) are the most recent development in underwater technology. Independent of the surface, battery powered and controlled by computers using various levels of artificial intelligence, these vehicles are programmed to carry out various underwater survey tasks. NURP and Sea Grant funded the initial development of the Odyssey series of AUVs at the Massachusetts Institute of Technology (MIT) Sea Grant College Program's Autonomous Underwater Vehicles Laboratory led by James G. Bellingham.

NURP continues to support AUV development. Designing a low-cost, multi-task AUV that wouldn't destroy a science budget if lost in the ocean was a top priority of investigators at the Long-term Ecosystem Observatory (LEO-15) off the coast of New Jersey. REMUS (Remote Environmental Monitoring Units) designed by WHOI engineer Chris von Alt with funding from NURP met this criteria. The torpedo-shaped tetherless submersible responds to an acoustic beacon emitted between nodes to follow a survey pattern. Plans are for each REMUS to be equipped with different kinds of sensors like video cameras, side scan sonars, current meters, and chemical sensors to measure conditions and parameters such as dissolved oxygen. REMUS will dock at a subsea transfer station to recharge its batteries and transfer its data through a fiber-optic cable to the shore.

Submersibles

Research submersibles carry humans directly to the midwater realms or the sea floor in many parts of the ocean. NURP routinely sponsors research that uses a wide variety of submersibles. With its fish bowl acrylic sphere, two scientists comfortably make observations at 920 m (3,000 ft) while inside the *Johnson-Sea-Link* (JSL) submersible. *JSL* is owned and operated by the Harbor Branch Oceanographic Institution (HBOI) and leased regularly to NURP scientists. For example, it enabled NURP scientists to study a variety of deep-sea communities in the newly developed continental shelf oil fields of the Gulf of Mexico.

Cooperative agreements between the Navy and other government agencies made Navy submersibles available for science and helped prolong their use, but cutbacks in federal spending have decreased the number of submersibles available for deep ocean exploration. Unfortunately, the *Turtle* was decommissioned in 1997, and the *Sea Cliff* was decommissioned the following year. This will leave the *Alvin* as the only U.S.-owned

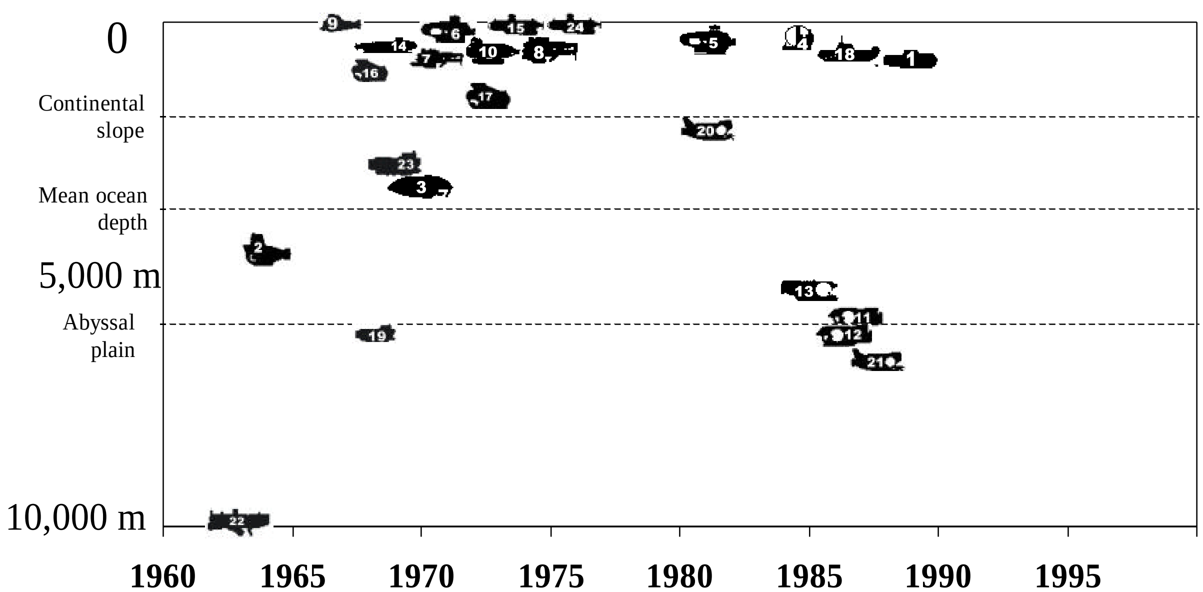


RON CATANACH

The Alvin is used by scientists in the deep sea

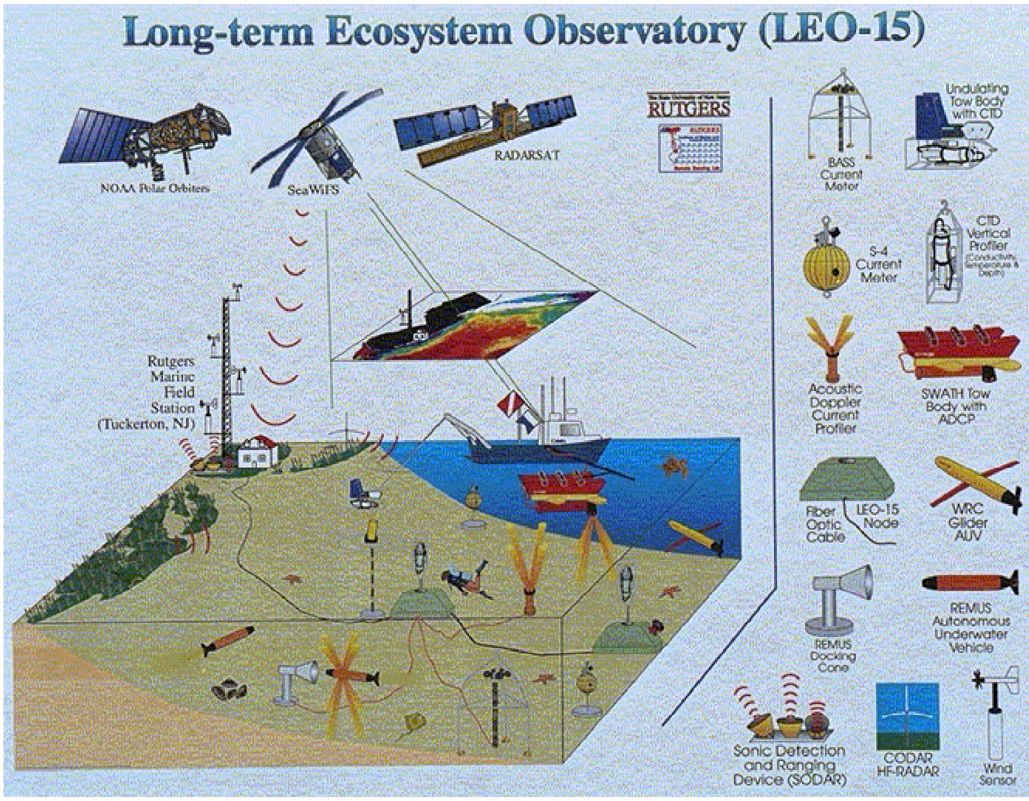
The blockbuster movie, *Titanic*, begins with footage of the celebrated wreck taken from the most renowned research submersible, *Alvin*. In 1956, engineer Allyn Vine of Woods Hole Oceanographic Institution (WHOI) attended a symposium in Washington, where it was resolved to develop a national program for manned undersea vehicles. The science community first obtained the *Trieste* bathyscaphe, but it was quite large and not very maneuverable—a better craft was needed for science. In 1964, Litton Systems delivered the DSV *Alvin* (named after Vine and the popular chipmunk) to Woods Hole. Following shallow tethered dives near Woods Hole, the first free dive took place on August 4 to a depth of 10 m (32 ft).

Research Submersibles



1 = 3gst9 4 = Deep Rover 7 = JSL I 10 = Mermaid II 13 = Nautile 16 = Pisces II 19 = Sea Cliff 22 = Trieste I
2 = Alvin 5 = Delta 8 = JSL II 11 = MIR I 14 = NR-1 17 = Pisces V 20 = Shinkai2000 23 = Turtle
3 = Cyana 6 = Gamma 9 = Makali'i 12 = MIR II 15 = PC-15, L1 18 = Saga 21 = Shinkai6500 24 = Clelia

Source: National Research Council, *Undersea Vehicles and National Needs*, 1996; NOAA's *The Ocean System - Use and Protection*, 1989.



NURP/MAB

Schematic of the Long-term Ecosystem Observatory off the Coast of New Jersey.

DSV used by scientists capable of reaching 4,500 m (14,760 ft). *Alvin*, built in 1964, has spent more than 21,500 hours submerged on almost 3,200 dives to an average depth of more than 2,000 m (6,400 ft). NURP has been a contributing partner with the Navy and the National Science Foundation in support of *Alvin's* research activities since the 1970s.

In the Pacific Ocean where deep coral reefs and fishery habitats remain largely unexplored, NURP's 69 m (223 ft) support vessel *Ka'imikai-O-Kanaloa (K-O-K)* used with the submersible *Pisces V* carries out deep ocean scientific research. The *Pisces V* is a three-person submersible with a depth capability of 2,000 m (6,600 ft). Two years ago, NURP researchers used the *K-O-K and*

NURP/HURL

Pisces V* on the *K-O-K.

Pisces V to reach the submarine volcano Loihi off the big island of Hawaii. Loihi erupted sparking the strongest seaquake ever recorded in the region. *Pisces V* was able to reach the collapsed lava dome 1,000 m (3,200 ft) below the sea surface within a few weeks after its eruption.

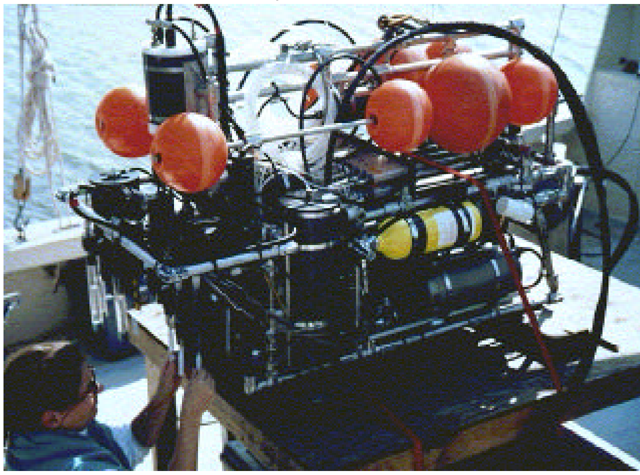
Seafloor Observatories

An innovative approach is being demonstrated by Rutgers University and the Woods Hole Oceanographic Institution (WHOI) at the LEO-15 Observatory at a 15-m (50 ft) depth on the inner continental shelf of New Jersey. We miss most events in the ocean because we don't have sensors in the ocean environment to continuously record what happens there. It took ten years of collaboration between Fred Grassle, director of the Institute for Marine Coastal Sciences at Rutgers University, and WHOI engineer Chris von Alt to realize this goal. LEO-15 is now the focus of a broad spectrum of research sponsored by NURP. Since its inception, more than 50 projects at LEO-15 have been supported with funding from the National Science Foundation, NURP, and the National Ocean Partnership Program.

"Nobody would run a laboratory now without Internet and electrical connections," Grassle said. "And now we have them at the bottom of the ocean." LEO-15 provides this kind of connection with more than a dozen different kinds of sensors at LEO-15 providing real-time information.

Plans for a Hawaii Undersea Geo-Observatory (HUGO) are underway with a fiber optic cable running to the submarine volcano Loihi where underwater seismic instruments are in place to record its eruptions. The submersible *Pisces V* will be available for servicing its instruments.

CLARE REIMERS



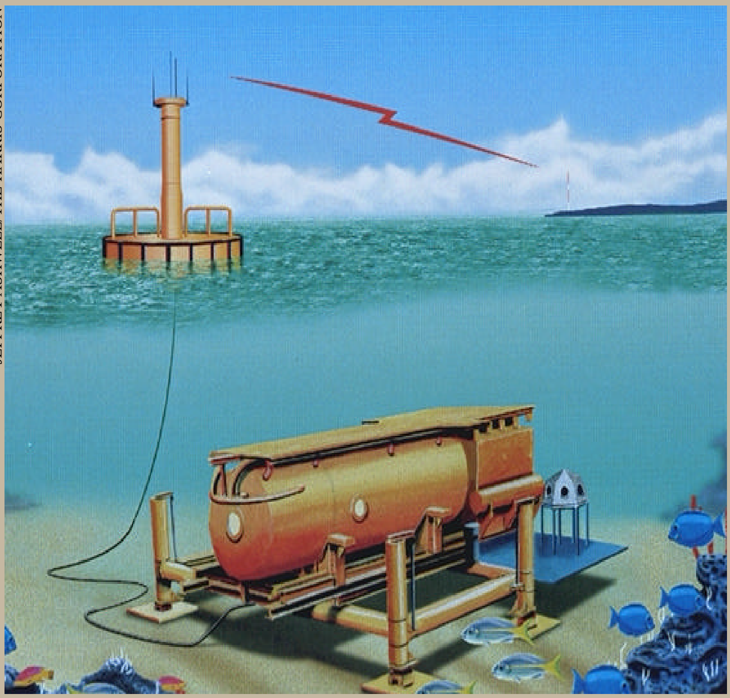
Benthic Shuttle System (BESS).

Survey and Sensor Systems—A Few Examples

New automated systems enhance the performance of existing platforms and vehicles, thereby reducing the need for new undersea vessels. An ROV-deployed Benthic Shuttle System (BESS), a flexible instrument package designed by NURP-funded researcher J. Val Klump, his colleagues at the University of Wisconsin, and David Lovalvo, president of Eastern Oceanics, has proved essential for studying the interactions of sediments and their overlying waters in the Great Lakes and in the Mid-Atlantic Ocean. Prior to BESS, no descriptions of dissolved chemicals had been attempted in water depths beyond the easy reach of SCUBA in the Great Lakes, primarily because no technology existed.

Instruments called microprofilers, which probe into sediment to take fine scale chemical measurements, have also been refined by NURP-funded researchers to make strides in our understanding of chemical interactions at the sediment-water interface. Chemical oceanographers Clare Reimers of Rutgers University and George Luther of the University of Delaware are using this innovative sampling technique in the New York Bight to successfully measure carbon cycling in the ocean important for understanding global climate change.

JEFFREY ASHWELL/THE HARRIS CORPORATION



The *Aquarius 2000*

The recent development of *Aquarius 2000* is an example of a NURP partnership with industry and academia. The *Aquarius* underwater laboratory has been redesigned to include an autonomous data/telemetry buoy that was developed in cooperation with the Harris Corporation and Harbor Branch Oceanographic Institution. The buoy will supply all of the life support and communications capabilities previously provided by a barge manned by up to four technicians. In addition, the new buoy will provide real-time data and video links from the sea floor laboratory back to the shore-based support laboratory and eventually to the world via the World Wide Web.

NURP Partnerships

During the past four years, the Navy's manned submersibles, *Turtle* and *Sea Cliff,* were made available to the science community through NURP. Use of the *NR-1* was also coordinated by NURP. The Navy's *NR-1*, with a depth capability of 724 m (2,375 ft), is the world's only nuclear powered research submarine. For wide area surveys and longer cruises, the *NR-1*, which can stay submerged for up to 30 days or more, has proven useful. For example, NURP-funded oceanographer Mary Scranton of the State University of New York at Stony Brook used the *NR-1* to study methane gas seeps in the Mid-Atlantic Bight. Scranton wanted to determine the contribution of this greenhouse gas to the atmosphere. Using this submarine's side-scan sonar to visualize pockmarks or chimneys that identify seeps along the continental shelf, she was then able to collect methane samples from the water column for her experiment.

A recent survey of the Massachusetts Bay for radioactive waste containers illustrates another collaborative partnership through NURP. In this case, NURP provided its ROV, the *Phantom S2*, which was fitted with a gamma spectrophotometer developed by the Department of Energy for detection of radioactivity underwater. The Environmental Protection Agency provided the funding for the ship and submersible, the Harbor Branch Oceanographic Institution (HBOI) donated the transit costs to get its ship and submersible to the Massachusetts Bay area, and the Raytheon Corporation donated its Fluorescence Imaging Laser Line Scan system (FILLS).

Japan, a recognized global leader in the undersea technology arena, is another NURP partner. Through the U.S.-Japan Cooperative Program in Natural Resources (UJNR), U.S. scientists can gain access to Japan's undersea assets. UJNR provides a forum for collaboration between U.S. scientists and their overseas colleagues. Through UJNR, NURP has supported numerous U.S. scientists participating on research cruises on the Japanese submersibles *Shinkai 2500* and the *Shinkai 6500*. UJNR's Diving Physiology and Technology Panel is chaired by NURP. NURP recently sponsored two Japanese physiologists who studied hyperbaric physiology at the University of Wisconsin.

NURP recently partnered with the Institute for Exploration (IFE) and the Jason Foundation to take advantage of a broad-based private educational outreach program. This year, the first phase of the agreement with NURP will involve IFE preparing to transfer advanced capabilities developed through Navy research for the Jason ROV to the *Kraken,* NURP's North Atlantic and Great Lakes Center's ROV. With sophisticated robotics, control, imaging, and mapping technologies, the improved *Kraken* will beome a state-of-the-art ROV used by NURP and IFE for undersea exploration and research.

The Shinkai 6500.

A Project Tomorrow educator provides elementary students with a hands-on lesson, focusing on biology of a sea urchin.

Outreach and Education

Science and technology are the cornerstone of our nation’s economic leadership. Maintaining this leadership can only be achieved through a partnership of scientists, students, educators, and the public. The research community must engage in activities that educate future scientists and engineers and inform the public about the results of their efforts to foster a scientifically literate citizenry prepared to make the difficult policy choices called for in balancing economic growth and environmental conservation. While the primary mission of NURP is scientific research, a small portion of the program is aimed at sharing the results of this research through partnerships with education and outreach programs. NURP programs involve hundreds of scientists each year throughout the world studying exciting new frontiers. We are uniquely positioned to meet the challenge of using this excitement to capture public attention and educate our future leaders.

Through the Internet, the scope of potential involvement and access to information is expanded to a global scale. Interactive technologies allow students and teachers to experience and study the oceans without leaving their schools. A Long-term Ecosystem Observatory at a 15 m (50 ft) depth (LE0-15) in the Atlantic Ocean gives hundreds of K-12 teachers and their classrooms access to real-time scientific data from the seafloor observatory. The Jason Project also reaches hundreds of thousands of students around the nation. Students participating in the Jason Project at the *Aquarius* chatted with scientists living in the underwater laboratory, observed how scientists conduct research from a nuclear submarine, and piloted an underwater robot around a coral reef.

This chapter focuses on how NURP enables students and educators to escape the confines of the classroom and textbooks, and sail with scientists on and into the sea.

Hands-on Science

The Aquanaut Program

For almost a decade, the Aquanaut Program (AP) annually has provided an average of 75 high school students and 14 teachers the chance to roll up their sleeves to participate in hands-on experience in marine research. The stimulating nature of advanced technologies used in modern oceanographic research, strong linkages between scientists, teachers, and students contribute to its success. Teachers and students get immersed in the culture of research, allowing them to experience the entire research process. The students learn how to use the technologies to conduct research. The mentor scientist is a positive role model who guides the research project from start to finish: providing background information on the importance of the topic, introducing the research methodologies, explaining the application of advanced technologies, and providing quality control on data collection, analysis and presentation. The research topics are not only relevant, but students care about them.

AP is a chance for teachers and students to job shadow a scientist where there are no canned problems and no canned solutions. "Kids get to see what the craft of a research scientist is, and how they deal with success and also with failure when things don't go as planned on a research cruise. Things like poor visibility and seasickness certainly factor into a mission," said Ivar Babb, director of NURP's North Atlantic and Great Lakes Center at the University of Connecticut at Avery Point. As a result of their efforts, teachers generally return to their classroom with fresher outlook on science, armed with new resources to develop marine science projects that they might not have thought of before. Student aquanauts often return to their high schools with better attitudes that result in better grade point averages, said Peter Scheifele, director of the Aquanaut Program based at NURP's North Atlantic and Great Lakes Center. A random survey of 100 aquanauts taken by NURP a year after they left the program showed that 92 percent of the students had gone on to college, with 48 percent choosing to major in math, science, and engineering as a direct result of participating in the program.

"It's really interesting to see the light bulb go on in students' heads," Scheifele said. "Whereas many of the students, before becoming Aquanauts, had no idea of the problems confronting the environment, they soon realize they can become a force in protecting the environment in their own daily lives."

NURP/UCAP

American School for the Deaf students operating the passive sonar suite tracking vessels and whales.

Interactive Science

Underwater Web Sites Take Students to the Ocean Floor

Internet history was made in 1996 when the world's only undersea laboratory devoted to science became the world's first underwater web site. Hundreds of thousands of students had a virtual porthole via video screens to experience how scientists conduct research from a specially designed underwater habitat called *Aquarius*, owned and operated by NURP. Understanding problems and opportunities in the oceans requires first-hand experience. Although the whole earth is impacted by the oceans, few people have the fortune to be on or in the ocean. "Since few teachers and students will ever go to sea," said Steven Miller, associate director of NURP's Southeastern and Gulf of Mexico Center, "we propose finding effective ways to bring the sea to them."

The *Aquarius* is a cylindrical chamber anchored to the seafloor in 15 m (50 ft) of water at the base of a coral reef off Key Largo, Fla. It enables scientists to live and work for up to ten days on the bottom. For two weeks in 1996, students, teachers, and researchers from all over the world joined together for a live broadcast of a scientific experience at the *Aquarius* as part of the Jason Project VII: Adapting to a Changing

DOUG KESSLING

Dr. Gerald Wellington gives watery lecture to high school students participating in Jason Project off Key Largo.

Sea. The Jason Project transports students via satellite to remote sites where scientists are engaged in research so they can closely examine the biological and geological development of the earth.

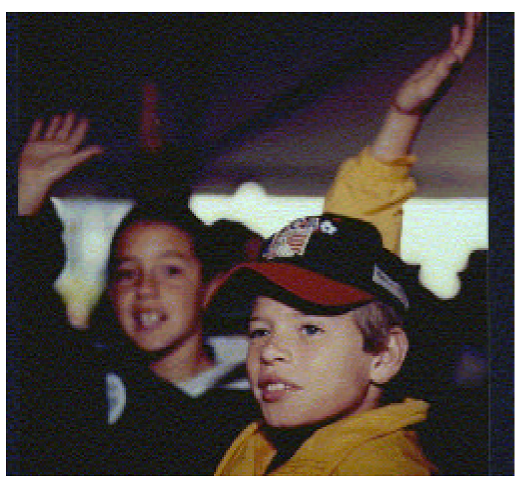
Video, telepresence, and web-based programs will be used to launch more education and outreach opportunities in marine science from the *Aquarius* in a way similar to that used in the Jason project. *Aquarius* was recently refurbished with state-of-the-art video, data and voice communications systems provided by the Harris Corporation, an international electronic communications company. Marine scientists will now be able to communicate underwater during excursions and transmit data in real time from a buoy secured to the seafloor to a shore base 13 km (8 mi) away. Announcements will be posted related to events of wide interest like coral disease epidemics and upwelling. News media with access to satellite transmission equipment will be able to present real-time views of scientists living and working underwater.

By training teachers to participate in at-sea scientific missions based at the *Aquarius* habitat and broadcasting their experiences at the *Aquarius* web site (http://www.uncwil.edu/nurc/Aquarius), the importance of marine science will be communicated in an exciting new way.

Mounting demands placed on marine and coastal resources have made it particularly important for students of all ages to understand how the environment and science effect their lives and future choices. The Institute of Marine and Coastal Sciences (IMCS) at Rutgers University has developed a professional development program for K-12 educators called Project Tomorrow to meet these growing needs.

Project Tomorrow offers classroom lessons and field trips for K-8 students that integrate the study of the ocean with the school's existing curriculum. IMCS is currently working with 15 schools throughout New Jersey in the creation of Ocean Weeks, where the school is immersed in the study of the ocean. IMCS also recently developed an innovative series of Internet-based instructional modules, which link classrooms with active research investigations at the Long-term Ecosystem Observatory (LEO-15), 15 m (50 ft) in the ocean. Because data is collected continuously and long-term at the fixed LEO-15 location, scientists, educators, and students have the ability to get a common sense view of the ocean via the Internet. Like the terrestrial ecologist who can walk along the forest floor, LEO-15 provides students with the ability to get a real-time connection to the ocean. These LEO-15 modules target middle school (6-8 grade) students and focus on teaching children how to think critically about the world around them.

This summer, IMCS is offering K-12 teachers research experience at the LEO-15 site. This program, funded through NURP and the National Ocean Partnership Program (NOPP), will partner classroom teachers with marine scientists working at the LEO-15 site. Together, this consortium of scientists and educators will develop new Internet materials to be used via the Internet global school network. Through LEO-15, real-world research experiences and training will be made available to students, some of whom will become tomorrow's scientists and engineers and all of whom will be challenged to make informed decisions on future environmental issues.



J. MCDONNELL

Hands-on Internet lessons focus on development of problem-solving and decision-making skills.

Appendix I

National Undersea Research Program Projects Funded for Fiscal Years 1995-1997

Healthy Oceans

1995 Florida Development Program: Keys-wide Monitoring of Coral Reef Health*
Miller, Steven L.
(University of North Carolina at Wilmington)

A Preliminary Investigation of Near Bottom Hydrographic Processes Affecting Sediment Transport on the New York Bight Shelf*
Glenn, Scott M.
(Rutgers, The State University of New Jersey)

A Synoptic Survey of Coral Reefs in the Florida Keys National Marine Sanctuary*
Ogden, John C.
(Florida Institute of Oceanography)

A Synoptic Survey of Coral Reefs in the Florida Keys National Marine Sanctuary and off Palm Beach, FL*
Hanisak, Dennis M.
(Harbor Branch Oceanographic Institution)

A Systematic Revision of the Caribbean Mussidae (*Scleractinia*)
Danaher, Deborah
(University of Maryland)

Acquisition of Continuous, *In Situ*, Chlorophyll Fluorescence at the LEO-15 Site*
Asper, Vernon L.
(University of Southern Mississippi, Stennis Space Center)

Algal Species Diversity and Composition as a Factor of Depth and Season in Deep Insular Reef Slope in the Bahamas
Ballantine, David L.
(University of Puerto Rico)

An Experimental Test of the Onshore-Offshore Predation Hypothesis
Aronson, Richard B.
(Dauphin Island Sea Lab)

Analysis and Interpretation of Video Transect Data From Coral Reefs in the Vicinity of Lee Stocking Island, Bahamas
Bright, Thomas J.
(Texas A&M University)

Bacterial Production in the Benthic Boundary Layer of Green Bay and Lake Michigan
Cuhel, Russell L.
(University of Wisconsin-Milwaukee)

Beach Erosion and Hurricane Protection Plan for Onslow Beach, NC
Cleary, William J.
(University of North Carolina at Wilmington)

Between Reef Comparsion of Internal Wave Impacts*
Leichter, James J.
(Stanford University)

Bioerosion in Deep Reef Environments and Microbial Endolithic Organisms as an Environmental Factor
Kiene, William E.
(J.W. Goethe University)

Bioerosion of Coral Reefs*
Feingold, Joshua S.
(Nova Oceanographic Center)

Bioerosion, Sediment Production, and Storm Dynamics in Onslow Bay
Riggs, Stanley R.
(East Carolina University)

Biogeochemistry of Manganese and Iron Reduction in Shelf Sediments
Reimers, Clare E.
(Rutgers, The State University of New Jersey)

Biological Processes on Deep and Shallow Coral Reefs*
Reaka-Kudla, Marjorie
(University of Maryland, College Park)

Bottom Boundary Layer Dynamics and Sediment Transport Observations of Velocity and Sediment Distributions*
Agrawal, Yogesh C.
(Sequoia Scientific Inc.)

Bottom-up Controls of Coral Reef and Seagrass Community Structure
Lapointe, Brian
(Harbor Branch Oceanographic Institution)

Carbon Budgets, Growth and Sexual Reproduction by Halimeda Across a Depth Gradient*
Smith, Celia
(University of Hawaii)

Carbonate Environments: Microbial Ecology and Bacterial Calcification Studies
Thompson, Joel B.
(Eckerd College)

Cargo Sweeping and Zebra Mussels: Quantitative Characteristics of Sonar Targets in Lake Ontario
Flood, Roger D.
(State University of New York at Stony Brook)

Chemical Ecology of Caribbean Demosponges*
Pawlik, Joseph
(University of North Carolina at Wilmington)

Chemical Orientation in the Marine Environment: High Resolution Measurement of Marine Chemical Signals and Quantifications of Chemical Orientation by Benthic and Pelagic Organisms
Moore, Paul A.
(Bowling Green State University)

Chronology and Isotope Geochemistry of Ground Waters in the Florida Keys and Offshore Areas*
Bohlke, Dr. John K.
(U.S. Geological Survey)

Coastal Erosion and Shoreface Processes off North Carolina
Cleary, William J.
(University of North Carolina at Wilmington)

Comparative Taphonomy of Life, Death and Fossil Caribbean Coral Assemblages, Key Largo, Florida*
Greenstein, Benjamin
(Smith College)

Controls on Infaunal Community Structure at Pacific Methane Seeps
Levin, Lisa A.
(University of California, San Diego)

Coral Bleaching: Mode of Release of Zooxanthellae
Muscatine, Leonard
(University of California, Los Angeles)

Coral Culture at Lee Stocking Island: A Feasibility Study
Mueller, Erich M.
(Mote Marine Laboratory)

Coral Recruitment Processes at Conch Reef*
Smith, Struan
(Bermuda Biological Station)

Coral Reef Monitoring
Lang, Judith C.
(University of Texas, Austin)

Cross-Shore Sediment Transport off a Replenished Beach: Carolina Beach/Ft. Fisher, North Carolina
Cleary, William J.
(University of North Carolina at Wilmington)

Deepwater Crevicular Fauna of the 'Wall' at Lee Stocking Island
Iliffe, Thomas M.
(Texas A&M University at Galveston)

Denitrification and Microbial Dynamics in Continental Shelf Sediments: Use of *In Situ* Methods*
Seitzinger, Sybil P.
(Rutgers, The State University of New Jersey)

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* These projects included cooperation with the National Marine Sanctuary Program, the National Estuarine Research Reserve, or the National Park Service.

Note: Lead principal investigators only are noted here.

Determination of Ground-water-Flow Direction and Rate Beneath Florida Bay, the Florida Keys and Reef Tract*
Shinn, Eugene A.
(U.S. Geological Survey)

Determination of Quantitative Relationships Between Coral Color
Maguire, Bassett
(University of Texas at Austin)

Development of Nationally Consistent Reef Resource Monitoring Programs Among Sanctuary Sites*
Score, David
(Gray's Reef National Marine Sanctuary)

Developmental Undersea Research in the South Atlantic Bight, 1995*
Potts, Thomas
(NURC/UNCW)

Differential Effects of UV-A and UV-B on Recovery and Acclimation of Reef Corals Stressed by Ultraviolet Light*
Wellington, Gerard M.
(University of Houston)

Discriminating Endemic from Opportunistic Predators at Hydrothermal Vents
Voight, Janet R.
(The Field Museum)

Distribution and Abundance of *Codium isthmocladum* off SE Florida
Carlson, Paul R.
(Flordia Marine Research Institute)

Distribution and Effects of Ship-Derived Ash and Coal Wastes: A Geochemical and Ecological Study of Sedimentary Deposits in Western Lake Ontario
Brownawell, Bruce J.
(State University of New York, Stony Brook)

Dynamics of Dissolved Organic Carbon at LEO-15
Wainwright, Sam C.
(Rutgers, The State University of New Jersey)

Early Succession, Persistence and Seep Affinities of Whale-fall Communities on the Northeast Pacific Slope
Smith, Craig R.
(University of Hawaii/Oceanography)

Ecology and Physiology of *Beggiatoa sp.* at Monterey Canyon Seeps: A Model of Novel, Sulfide-Driven, Bacterial Denitrification?*
Nelson, Douglas C.
(University of California, Davis)

Effects of Damselfish Activities on the Settlement, Recruitment, and Survival of Corals Under Different Environmental Conditions
Sabat, Alberto M.
(University of Puerto Rico)

Effects of Nutrient Enrichment on Chemical Composition and Metabolic Rate of Corals from Impacted and Non-Impacted Environments
Cook, Clayton B.
(Harbor Branch Oceanographic Institution)

Effects of Sludge Carbon Deposition on Benthic Metabolism, Macrofauna Activity and Redox Zonation
Sayles, Frederick L.
(Woods Hole Oceanographic Institution)

Effects of Sludge Deposition on Benthic Populations in Deep-Sea Sediments of the Continental Rise in the Vicinity of Municipal Dumpsite - 106 (LEO-2500)
Grassle, J. Frederick
(Rutgers, The State University of New Jersey)

Effects of Water Movement on Corals: Particle Capture, Prey Behavior, and Growth Rate*
Sebens, Kenneth P.
(University of Maryland)

Environmental and Biological Aspects of Coral Reef Degradation in the Florida Keys: Algal and Bacterial Diseases of Corals*
Richardson, Laurie L.
(Florida International University)

EPA-Cape Arundel Dump Site Assessment
Tomey, David
(U.S. Environmental Protection Agency)

Evaluation of Rates of Change in Bahamian Deep-Water (30-300M) Communities
Liddell, W. David
(Utah State University)

Extensive Collections of Offshore Seaweed for Chemical and Ecological Compounds
Hay, Mark E.
(University of North Carolina at Chapel Hill)

Field Support to Continue Long-term Sampling of Stressed Benthic Foraminiferal Populations in the Florida Keys*
Hallock-Muller, Pamela
(University of South Florida)

Fungal Diseases of Sea Fans*
Harvell, Drew C.
(Cornell University)

Gametogenic Ecology of a Deep-Sea Hydrothermal Vent Community
Van Dover, Cindy Lee
(University of Alaska, Fairbanks)

Gas Hydrate Mounds: Sites of Metastable Seafloor and High Microbial Productivity
Roberts, Harry H.
(Louisiana State University)

Genetic Determination of Different Species of Endosymbiotic Dinoflagellates and Specificity of Coral-Microalgal Symbioses at Lee Stocking Island
Reichman, Jay
(University of Texas at Austin)

Genetic Variation of *Montastrea cavernosa* along the Florida Keys Reef Tract*
Sammarco, Dr. Paul
(LUMCON)

Growth and Productivity of *Ridgeia piscesae* and Trophic Interactions within Vestimentiferan Communities in Different Vent Environments
Fisher, Charles R.
(Pennsylvania State University)

Habitat-Specific Differences in Sponge Growth: The Role of Scope for Growth and Phenotypic Plasticity*
Patterson, Mark R.
(VIMS - College of William and Mary)

Human Pathogens in Canals and Confined Bodies of Water in the Florida Keys, Abundance and Human Health Risks*
Rose, Joan B.
(University of South Florida)

Hydrothermal Activity in Yellowstone Lake, Wyoming and its Influence on the Distribution and Activity of Micro- and Macro-Organisms*
Maki, James S.
(Marquette University)

Impact of Injection Wells and Septic Tanks on the Key Largo Reef Environment: Tracer Studies*
Paul, John H.
(University of South Florida)

In Situ* Observations and Sampling of Contaminated Groundwater in the Florida Keys
Chanton, Jeffrey
(Florida State University)

In Situ* Observations of Coastal Upwelling and Sediment Transport in the Middle Atlantic Bight
Glenn, Scott M.
(Rutgers, The State University of New Jersey)

***In Situ* Sediment-Water Exchange Process Studies in the Great Lakes**
Klump, J. Val
(University of Wisconsin-Milwaukee)

Interstitial Water, Thermal Gradient, and Submarine Discharge Studies in Onslow Bay
Spivack, Dr. Arthur
(University of North Carolina at Wilmington)

Intraspecific Diversity and Ecological Zonation in Coral-Algae Symbiosis: A Compara-

tive Study
Knowlton, Nancy
(Smithsonian Tropical Research Institute)

Investigation of Carbon Cycling on the Reef Tract in South Florida*
Swart, Peter K.
(University of Miami/RSMAS/MAC)

Investigation of Deep Water Bank Accumulation at Log Transfer and Storage Facilities
O'Clair, Charles
(Auke Bay Fisheries Laboratory, NMFS)

Investigation of Sedimentation in Ambrose Channel Lower New York Harbor
Bohlen, Dr. Frank W.
(University of Connecticut, Avery Point)

Investigation of the Biosynthetic Pathways in *Eudistoma olivaceum* and Other Caribbean Invertebrates in the Proximity of Lee Stocking Island, Bahamas
Baker, William J.
(Florida Institute of Technology)

Investigations of the Chemical and Physical Defenses of Reef and Mangrove Demosponges*
Pawlik, Joseph
(University of North Carolina at Wilmington)

Investigations of the Impact of Light Penetration and Water Column Stratification on Community Structure in the Gulf of Maine/Georges Bank
Frank, Tamara M.
(Harbor Branch Oceanographic Institution)

Larval Biology and Gametogenesis in a Deep-Sea Community With Continuous Nutrient Input: Cold Seeps on the Louisiana Slope
Young, Craig M.
(Harbor Branch Oceanographic Institution)

Levels and Biological Effects of Organic and Inorganic Contaminants in Caribbean Scleractinian Corals
Harrison, Peter
(Southern Cross University)

Limits of Bathymetric Distribution in Deep-Sea Echinoderms: the Role of Embryonic Pressure Tolerances
Young, Craig M.
(Harbor Branch Oceanographic Institution)

Manned Submersible Reconnaissance of the Torpedoed Oil Tanker *SS Montebello*
Hunter, Jack
(California Department of Transportation)

Marine Cave and Crevicular Fauna of the Exuma Islands
Iliffe, Thomas M.
(Texas A&M University at Galveston)

Mass Transfer in Corals: Effects of Turbulent Flow*
Wethey, David S.
(University of South Carolina)

Mechanisms of Destruction on Florida Coral Reefs*
Reaka-Kudla, Marjorie
(University of Maryland, College Park)

Mechanisms of Preservation of Skeletal and Organic Remains and Death Assemblage Formation in Carbonate Shelf Sediments
Powell, Eric N.
(Texas A&M University)

Mobile Predators at Northeast Pacific Vents
Voight, Janet R.
(The Field Museum)

Molecular Assessment of the Effect of Ultraviolet Radiation on Coral Reef Microbial Ecology*
Jeffrey, Wade H.
(University of West Florida)

Molecular Basis for Stable Carbon Isotope Discrimination in Hydrothermal Vent Ecosystems: A Survey of Pacific Vent Symbioses
Cavanaugh, Colleen M.
(Harvard University)

Monitoring of Benthic Faunal Responses to Sediment Removal Associated With the Carolina Beach and Vicinity-Area South Project
Posey, Martin E.
(University of North Carolina at Wilmington)

Monitoring of Sewage-Derived Organic Material in Deep-Sea Food Webs at Dumpsite 106
Van Dover, Cindy Lee
(University of Alaska, Fairbanks)

Monthly Hydrographic Surveys and Water Column Sampling Across the Shelf in Onslow Bay, NC
Spivack, Dr. Arthur
(University of North Carolina at Wilmington)

Monthly Monitoring of Bioerosion and Nutrient Levels at Florida Keys Coral Reefs*
Reaka-Kudla, Marjorie
(University of Maryland, College Park)

Origin of Particulate Matter and Distribution of HOC in Benthic Nepheloid Layer of Large Lakes
Atkinson, Joseph F.
(State University of New York at Buffalo)

Patch Dynamics of Cerianthids and Its Consequences in Structuring Benthic Communities in the Gulf of Maine
Watling, Leslie E.
(University of Maine)

Phenotypic Plasticity Among Tropical Reef Corals: Implications for Population Dynamics Under Changing Environmental Conditions*
Edmunds, Peter J.
(California State University, Northridge)

Physical Oceanography of Exuma Sound
Hickey, Barbara M.
(University of Washington)

Physiological and Biochemical Correlates of Bleaching During a Natural Stress Event in the Florida Keys*
Gleason, Dr. Daniel
(Georgia Southern University)

Phytoplankton Biomass at LEO-15 and the Calibration of *In Situ* Fluorometers
Schofield, Oscar
(Rutgers, The State University of New Jersey)

Precision Sampling and Characterization of Lake Ontario Sediments Affected by Ship-Derived Wastes
Brownawell, Bruce J.
(State University of New York, Stony Brook)

Predation by the Physonect Siphonophore *Nanomia cara*
Youngbluth, Marsh J.
(Harbor Branch Oceanographic Institution)

Productivity, Longevity and Life Histories of Vestimentiferans and Mussels at Cold Seeps in the Gulf of Mexico
Fisher, Charles R.
(Pennsylvania State University)

Rapid Response Project: Rhode Island Oil Spill
NURC-UCAP
(University of Connecticut - Avery Point)

Rapid Response Projects in the Florida Keys: Support for Coral Reef Research from Key Largo Support Base*
Miller, Steven L.
(University of North Carolina at Wilmington)

Rapid Response Projects in the South Atlantic Bight: Post-Hurricane Investigations and Collaborative Projects with other NURP Centers
Shepard, Andrew
(University of North Carolina at Wilmington)

Rates and Magnitudes of Trace Metal Redistribution in Sediments Following the End of SludgeDumping at the 106-Mile Site
Bothner, Michael H.
(United States Geological Survey at Woods Hole)

Real-Time Acoustic Imaging of the Bottom and Bottom

Boundary Layer at the LEO-15 Site*
Irish, James D.
(Woods Hole Oceanographic Institution)

Regional Variability in the Impact of Internal Bores on Florida Coral Reefs*
Denny, Mark W.
(Stanford University)

Remote Investigations and Sampling of Epibenthic Particle Accumulation in the Columbia River Estuary Turbidity Maximum
Simenstad, Charles
(University of Washington)

Reproductive Biology and the Limits of Bathymetric Distribution in Lithistid Sponges and Stalked Crinoids
Young, Craig M.
(Harbor Branch Oceanographic Institution)

Reproductive Success of Broadcast Spawning Gorgonians*
Lasker, Howard R.
(State University of New York at Buffalo)

Reproductive Success, Larval Dispersal, and Recruitment of an Endangered Sea Star *Oreaster reticulatus*
Scheibling, Robert E.
(Dalhousie University)

ROV Habitat Characterization of Gray's Reef NMS*
Score, David
(Gray's Reef National Marine Sanctuary)

ROV Mapping of Benthic Habitats and Communities at McMurdo Station, Antarctica
Oliver, John S.
(Monterey Bay Aquarium Research Institute/Moss Landing)

ROV Support for Long-term Monitoring in Gray's Reef National Marine Sanctuary*
Bohne, Reed M.
(Gray's Reef National Marine Sanctuary, NOAA/NOS/OCRM)

Sea Urchins in Seagrasses: An Experimental Examination of the Impact of Chronic Sea Urchin Grazing on the Turtlegrass Habitats in the Florida Keys*
Valentine, John F.
(University of South Alabama)

Seasonal Monitoring of Tissues of Four Species of Caribbean Reef Corals*
Fitt, William K.
(University of Georgia)

Seasonal Monitoring of Zooxanthellae Size, Biomass, and Energetic Content in Reef Building Corals
Kempf, Stephen
(Auburn University)

Seasonal Patterns in Tissue Biomass and Zooanthellae in Floridean Corals*
Fitt, William K.
(University of Georgia)

Seasonal Variation in a Zooxanthellate Reef Coral and Fire Coral and Effect of Transplantation
Fitt, William K.
(University of Georgia)

Sediment Irrigationand Benthic Fluxes on the Continental Margin, N.W. Atlantic
Martin, William R.
(Woods Hole Oceanographic Institution)

Sedimentary and Fluid Dynamics on the Shoreface and InnerShelf off Wrightsville Beach, North Carolina
Pilkey, Orrin H. Jr.
(Duke University)

Selfing, Outcrossing, and Fertilization Success in Hermaphroditic Reef-Building Corals*
Gleason, Daniel F.
(University of Houston)

Sourcing and Isolation of Marine Microorganisms for Drug Discovery
LaRoche, Elizabeth
(Phytera, Inc.)

Spatial and Temporal Variability in On-Shore Flux: Pulsed Delivery of Nutrients, Plankton and Larvae to Conch Reef by Internal Waves*
Denny, Mark W.
(Stanford University)

Spatial Heterogeneity and Coral Recruitment: Ecological Implications and Physiological Adaptations*
Edmunds, Peter J.
(California State University, Northridge)

Structure, Succession and Phylogenetic Affinities of Deep-Sea Whale-Fall Communities on the Northeast Pacific Slope
Smith, Craig R.
(University of Hawaii/Oceanography)

Submersible Survey of Benthos at the Proposed A-J Mine Submarine Tailings Disposal Site
Stekoll, Michael
(Juneau Center, School of Fisheries & Ocean Sciences, Univ. of Alaska-Fairbanks)

Suboxic/Anoxic Diagenesis in Reef Frameworks and Resulting Nutrient Fluxes*
Sansone, Francis J.
(University of Hawaii/Soest/ Oceanography)

The Bleaching Response of the Reef Building Coral *Montastraea annularis* Containing Different Zooxanthellae Genotypes*
Wellington, Gerard M.
(University of Houston)

The Dynamics of Oxygen Uptake by Shelf Sediments*
Reimers, Clare E.
(Rutgers, The State University of New Jersey)

The Effect of Florida Bay Waters on Coral Growth on the Florida Keys*
Swart, Peter K.
(University of Miami/RSMAS/ MAC)

The Effect of Small Scale Temporal and Spatial Variation in the Environmental Factors Causing Coral Bleaching*
Edmunds, Peter J.
(California State University, Northridge)

The Effects of Nutrient Loading on Growth of Halimeda*
Laing, Katie
(University of North Carolina at Wilmington)

The Effects of Sponges on Water Column Processes: Implications for the Management of Coral Reefs*
Patterson, Mark R.
(VIMS - College of William and Mary)

The Historical Influence of the Output from Florida Bay on the Growth of Corals of the Florida Reef Tract*
Swart, Peter K.
(University of Miami/RSMAS/ MAC)

The No-Take Zones of the Florida Keys National Marine Sanctuary: An Inter-Disciplinary Study of the Dynamics of Coral Reef Benthic Communities*
Ogden, John C.
(Florida Institute of Oceanography)

The Photic Ecology of Coral Reef Environments and the Impact of Human Activity Upon It*
Cronin, Thomas W.
(University of Maryland, Baltimore County)

The Role of Resuspended Beach Sediments on Coral Reef Stress and Health: Implications for Management of Coral Reef Ecosystems*
Patterson, Mark R.
(VIMS - College of William and Mary)

The Sediment 'Reference Concentration' Distribution at LEO-15 and Its Relationship to Waves and Currents*
Agrawal, Yogesh C.
(Sequoia Scientific Inc.)

The Use of Seagrasses to Determine the Sources of

Natural and Anomalous Nutrient Inputs in the Florida Keys Marine Sanctuary: Phase II-Year 2*
Zieman, Joseph C.
(University of Virginia)
Time Series of High Resolution Observations of Gradients in Pigment Fluorescence at LEO-15 Using a Multi-Sensor Fiber Optic Fluorometer*
Lohrenz, Steven E.
(University of Southern Mississippi, Stennis Space Center)

Ultraviolet Radiation Induced DNA Damage in Coral Reef Microbial Communities*
Jeffrey, Wade H.
(University of West Florida)

Upper Keys Reef Tract Circulation Study*
Smith, Ned P.
(Harbor Branch Oceanographic Institution)

Utility of ROV's for the Identification and Assessment of Marine Anthropogenic Debris at McMurdo Station, Antarctica
Kvitek, Dr. Rikk
(Moss Landing Marine Labs)

UV Light Monitoring*
Wellington, Gerard M.
(University of Houston)

Variability and Sources of Trace Metals in the Inner Shelfwater Column, New York Bight*
Sherrell, Robert M.
(Rutgers, The State University of New Jersey)

Outreach/ Education

Bringing the Ocean into the Precollege Classroom Through Field Investigations at a National Underwater Laboratory*
De Luca, Michael
(Rutgers, The State University of New Jersey)

Cooperative Engineering Education Projects
Rae, Graeme
(Florida Institute of Technology)

Ecological and Physiological Studies of Polyunsaturated Fatty Acid Metabolism in Marine Macrophytic Chlorophytes
Jacobs, Robert
(University of California, Santa Barbara)
Education Opportunites for Students in Summer Ventures in Science and Mathematics
Hall, Jack
(University of North Carolina at Wilmington)

Filming of the HMS *Britannic* in the Mediterranean
Ballard, Dr. Robert
(WHOI)

Great Lakes Book Project
NURC-UCAP
(University of Connecticut - Avery Point)

Jason Project*
Ballard, Dr. Robert
(WHOI)

Jason VII: Adapting to a Changing Sea
Ballard, Dr. Robert
(WHOI)

Marine Education: Field Experiences for Gifted High School Students and Diver Training for Minority Undergraduates*
Shepard, Andrew
(University of North Carolina at Wilmington)

NOAA/NITROX Diver Training Seminar with Savannah State College and Gray's Reef National Marine Sanctuary*
Bohne, Reed M.
(Gray's Reef National Marine Sanctuary, NOAA/NOS/OCRM)

NURC/CT DEP Long Island Sound Cooperative Research Program
Auster, Peter J.
(University of Connecticut, Avery Point)

Operation Pathfinder: Hands-on Science for Middle School Teachers
Spence, Lundie
(North Carolina State University)

Pathfinder: Reconnaissance Diving on Loihi to Determine Safe and Optimum Dive Sites
Malahoff, Alexander
(University of Hawaii)

Summer Ventures: Hands-on Science for High School Students and Teachers
Shafer, Karen
(University of North Carolina at Wilmington)
The Aquanaut Program*
Babb, Ivar
(University of Connecticut - Avery Point)

Predicting Environmental Change

A Decadal and Centennial Scale Record of Shallow Thermocline/Sea Surface Temperature From Calcifying Sponges, Exuma Sound, Bahamas
McNeill, Donald F.
(University of Miami)

Active Faulting on the Oregon and Washington Continental Shelf: Implications for Earthquake Potential and Crustal Rotation
Kulm, LaVerne D.
(Oregon State University)

Age-dependent Mixing of Deep-SeaSediments: A Test of Predictions on the Hawaiian Slope
Smith, Craig R.
(University of Hawaii/Oceanography)

Applications and Refinement of Seafloor Geodetic Techniques on the Juan De Fuca Ridge
Spiess, Fred N.
(University of California, San Diego)

Assessing the Recent Volcanic History and Geology of the Hydrohermal Vents at the Summit of Loihi Seamount
Garcia, Michael O.
(University of Hawaii/Geology & Geophysics)

Chemical Monitoring of Hydrothermal Venting on Loihi Seamount, Hawaii
McMurtry, Gary M.
(University of Hawaii/Oceanography)

Climate Records from Hawaiian Deep-Sea Corals
Dunbar, Robert B.
(William Marsh Rice University)

Development of Eastern Caribbean Shelf-Edge Reefs: Implications for Carbonate Platform Development and Reef Drowning
Hubbard, Dennis K.
(University of New Orleans)

Extent and Depth of Landsliding on the Submarine North Flank of Molokai
Holcomb, Robin T.
(United States Geological Survey at Seattle)

Geologic Framework of Outer Shelf-Upper Slope Carbonate Structures, Northeast Gulf of Mexico: Implications for Lake Quaternary Eustatic Sea Level Fluctuations and Regional Climate/Paleoecological Variability
Schroeder, William W.
(University of Alabama)

Hydrothermal Vent and Fluid Chemistry at Loihi Seamount, Hawaii
McMurtry, Gary M.
(University of Hawaii/Oceanography)

In Situ* Collection and Monitoring of Natural Gas Hydrate by Use of the *Johnson-Sea-Link
MacDonald, Ian R.
(Texas A&M University at College Station)

***In Situ* Microelectrode Measurements in the Great Lakes**
Reimers, Clare E.
(Rutgers, The State University of New Jersey)

***In Situ* Sampling of Outcropping Glacial and Glaciomarine Sediments and Sedimentary Bedforms in the Gulf of Maine**
Belknap, Daniel F.
(University of Maine)

Loihi Post-Crisis
Cowen, James P.
(University of Hawaii/Soest/Oceanography)

Modified Side-Scan Sonar Imaging of Carbonate Platform Margins: A Skewed View
Boss, Stephen
(University of Arkansas)

New Lessons on the Relationships between Magmatic Processes, the Subsurface Biosphere and the Ocean at an Intra-Transform Extensional Basin: Blanco Fracture Zone, Northeast Pacific
Embley, Robert W.
(United States Department of Commerce/NOAA/PMEL, Newport)

Origin and Emergence of Mendocino Ridge
Fisk, Martin R.
(Oregon State University)

Preservation of Skeletal and Organic Remains and Death Assemblage Formation in Continental Shelf and Slope Sediments, Gulf of Mexico
Powell, Eric N.
(Texas A&M University)

Quaternary Development of the Florida Keys Carbonate Platform-Relative Influence of Sealevel Fluctuations and Geostrophic Currents along a Windward Margin*
Toscano, Marguerite A.
(University of South Florida)

Submarine Hyaloclastites on Loihi Volcano: Eruption Dynamics and Fragmentation Mechanisms in the Depth Transition to Explosive Eruptions
Batiza, Rodey
(University of Hawaii/Geology & Geophysics)

Submerged Habitat and Lake-Level Fluctuations in Lake Malawi
Kornfield, Dr. Irv
(University of Maine)

Submersible and Remote Vehicle Investigations of Cascadia Forearc Processes: Forearc Deformation, Slope Failure, and Earthquake Potential
Goldfinger, Chris
(Oregon State University)

Temporal Evolution of Loihi Seamount Following the 1996 Seismic Event
Sansone, Francis J.
(University of Hawaii/Soest/ Oceanography)

The Fate of Algal Carbon in Continental Slope Sediments: A Multitracer Experiment
Blair, Neal
(North Carolina StateUniversity)

Sustainable Fisheries

1996 Development: Fisheries Oceanography in the South Atlantic Bight
Wicklund, Robert
(University of North Carolina at Wilmington)

Acoustic and Archival Tagging of Bluefin Tuna at Cape Hatteras
Block, Barbara
(Hopkins Marine Station)

An Experimental Test of Predator-Induced Density-Dependent Mortality in a Temperate Reef Fish
Carr, Mark
(University of California, Santa Barbara)

Artificial Spawning and Larval Rearing of Diadema *Antillarum*
Capo, Thomas
(University of Miami)

Assessment of Benthic and Benthopelagic Predator Fauna on Georges Bank
Madin, Lawrence P.
(Woods Hole Oceanographic Institution)

Collection of Eel *Leptocephali* for Determination of Gycosamino-Glycan Composition
Pfeiler, Edward
(Instituto Technologico Y Estudios Superiores De Monterrey Institution)

Control of Recruitment of the Surf Clam, *Spisula solidissima*, and Other Benthic Species of Continental Shelf Habitats*
Grassle, Judith P.
(Rutgers, The State University of New Jersey)

Coupling of Gulf Stream Water Intrusions and Arrival of Pre-Settlement Stages of Snapper-Grouper Species at a Mid-Shelf Reef, Onslow Bay, NC
Lindquist, David G.
(University of North Carolina at Wilmington)

Detection of Actively Used Lake Trout Spawning Reefs and Assessment of Egg and Larval Vulnerability to Sculpins
Janssen, John
(Loyola University)

Development of Mating Aggregations of Tanner Crab, "*Chionoecetes bairdi*"
Stevens, Bradley G.
(United States Department of Commerce/NOAA/NMFS/AFDC - Kodiak)

Dispersal and Population Genetics of Seamount Benthos
France, Scott C.
(Woods Hole Oceanographic Institution)

Ecology of Deep Water American Lobster (*Homarus americanus*): Distribution, Habitat Utilization and Recruitment Processes
Steneck, Robert S.
(University of Maine)

Effects of Early Summer Upwelling and Downwelling on Surfclam Settlement at LEO-15*
Grassle, Judith P.
(Rutgers, The State University of New Jersey)

Effects of Scallop Dredging on Benthic Communities of Georges Bank
Collie, Jeremy
(University of Rhode Island)

Effects of Trawling on the Sediment Microbiota of Stellwagen Bank*
Cahoon, Lawrence B.
(University of North Carolina at Wilmington)

Elevated Invertebrate and Fish Production in Submarine Canyons: Effects of Macrophyte Detritus
Dayton, Paul K.
(University of California, San Diego)

Experimental Analysis of Recruitment Processes in Queen Conch: Metamorphosis and Early Juvenile Growth*
Stoner, Allan W.
(Caribbean Marine Research Center)

Fish Nursery Habitats on the New York Bight Continental Shelf*
Cowen, Robert K.
(State University of New York at Stony Brook)

FORECAST - Larval Ecology and Recruitment Dynamics in the Queen Conch
Stoner, Allan W.
(Caribbean Marine Research Center)

FORECAST - Recruitment and Metapopulation Dynamics in the Caribbean Spiny Lobster and Nassau Grouper
Lipcius, Romuald N.
(VIMS, College of William and Mary)

Habitat Alteration Due to Mobile Fishing Gear: A Temporal Study of Selected Sites in the Gulf of Maine
Watling, Leslie E.
(University of Maine)

Identifying the Brook Stock for Coastal Populations of the American Lobster (*Homarus americanus*)
Steneck, Robert S.
(University of Maine)

***In Situ* Observations on the Distribution and Behavior of Juvenile and Adult Walleye Pollock (*Theragra chalcogramma*) in Relation To Oceanographic Conditions in the Bering Sea**
Brodeur, Richard D.
(United States Department of Commerce/NOAA/NMFS/ AFSC-Seattle)

***In Situ* Quantification of Zooplankton Aggregation Mechanisms using the Jason ROV on Georges Bank**
Davis, Cabell S.
(Woods Hole Oceanographic Institution)

Investigation of Insular Slope Fishery Habitats off Oahu and Identification of Bottomfish Nursery Grounds in Relation to Coastal Discharge
Grau, E. Gordon
(University of Hawaii at Kaneohe)

Juvenile Sturgeon Habitat Use in the Hudson River
Haley, Ms. Nancy
(NOAA/NMFS)

Leptocephalus Otolith Validation
Torres, Jose
(University of South Florida)

Marine Tropical Ornamental Fish Aquaculture Technology and Impact of Eel Predation on Newly Recruited Coral Reef Fishes
Shenker, Jonathan M.
(Florida Institute of Technology)

Monitoring of Fish Reserves in the FKNMS*
Bohnsack, James A.
(United States Department of Commerce/NOAA)

Movements of Fishes Associated With Natural Refugia in Monterey Bay: Implications for Marine Reserves in Fishery Management*
Starr, Richard M.
(Moss Landing Marine Laboratory)

NMFS Bluefin TunaSurvey off Cape Hatteras, NC
Rinaldo, Dr. Ronald
(NOAA/NMFS)

NURC/USGS Stellwagen Bank National Marine Sanctuary Habitat Mapping and Distribution of Living Marine Resources*
Auster, Peter J.
(University of Connecticut, Avery Point)

Observation of Beluga Feeding Habitat in the Arctic
St. Aubin, Dr. David
(Mystic Marine Life Aquarium)

Oceanography and Recruitment Processes in Exuma Sound
Hickey, Barbara M.
(University of Washington)

Physical Oceanography of Exuma Sound
Hickey, Barbara M.
(University of Washington)

Population Dynamics of Reef Fishes: Multiple Processes at Multiple Scales
Hixon, Mark A.
(Oregon State University)

Population Ecology of Great Barracuda in the Florida Keys National Marine Sanctuary*
Helfman, Gene S.
(University of Georgia)

Positive Feedback Mechanisms Among Seagrasses, Sediment Nutrients and Fish Recruitment to Reef Structures
Nelson, Walter
(Florida Institute of Technology)

Predatory Roles of Siphonophores in Monterey Bay: Implications for Marine Reserves in Fishery Management*
Youngbluth, Marsh J.
(Harbor Branch Oceanographic Institution)

Recruitment and Population Dynamics of Coral-Reef Fishes: A Multifactorial Analysis
Hixon, Mark A.
(Oregon State University)

Recruitment to Sargassum by Mobile Sub-Adult Pelagic Fishes
Moser, Mary L.
(University of North Carolina at Wilmington)

Recruitment, Metapopulation Dynamics, and Stock Enhancement of the Caribbean Spiny Lobster
Lipcius, Romuald N.
(VIMS, College of William and Mary)

Reproductive Strategies and Their Contribution to Gene Flow and Population Recruitment in the Commercially Important Squid *Loligo pealei*
Hanlon, Dr. Roger T.
(Marine Resources Center)

Ringed Seal Diving Behavior and Prey Distribution
Kelly, Brendan
(University of Alaska, Fairbanks)

Sampling Pulsed Food and Larval Supply With Replicate Pumps: Variation Along Depth Gradients
Witman, Jon D.
(Brown University)

Seaweed Beds as Critical Habitats for Recruiting Fishes on Temperate Reefs*
Hay, Mark E.
(University of North Carolina at Chapel Hill)

Seaweed-Coral-Herbivore Interactions on Coral Reefs*
Hay, Mark E.
(University of North Carolina at Chapel Hill)

Spawning and Recruitment in Gag (*Mycteroperca microlepis*): Rapid Identification and Location of Spawning Grounds
Sedberry, George R.
(South Carolina Marine Resources Research Institute)

Subtidal Landscapes: The Role of Habitat Variability on the Distribution of Fishes and Associated Fauna*
Auster, Peter J.
(University of Connecticut, Avery Point)

The Cape Hatteras Gulf Stream Front as an Aggregator of the Pelagic Stages of Tuna and Mackerel: Sampling with Light-Traps Across the Gulf Stream Front
Lindquist, David G.
(University of North Carolina at Wilmington)

The Effects of Fishing on the Structure and Function of Spawning Aggregations of Gag (*Myceteroperca microlepis*) and Scamp (M. *Phenax*) in the Atlantic and Gulf of Mexico
Grimes, Churchill
(NMFS, SEFSC)

The Role of Floating Sargassum Habitat in Mediating Predator-Prey Interactions among Pelagic Fishes on the Continental Shelf of North Carolina
Peterson, Charles H.
(University of North Carolina at Chapel Hill)

The Southern California White Abalone Stock Assessment Survey
Davis, Gary E.
(United States Biological Service)

Use of a Novel Gear Type to Evaluate the Association of Juvenile Scombroids with the Gulf Stream Front
Hare, Dr. Jonathan
(NOAA/NMFS)

Technology Development and Operations

Applications of Geographic Information System (GIS) to *In Situ* Dive Management and Research
Prisloe, Sandy
(Envirographics)

Aquarius* UnderseaLaboratory: Preparation and Re-engineering for the 21st Century
Borne, Chris
(University of North Carolina at Wilmington)

Construction, Testing and Calibration of a Drag Balance for Direct Measurements of Bottom Shear Stress*
Rankin, Kelly L.
(Steven Institute of Technology)

Data Communications Upgrades for ZAPS-Towed Fiberoptic Fluorometer Sled
Collier, Robert W.
(Oregon State University)

Design, Construction, and Deployment of a Portable, Flexible, Light-Weight, Hydrothermal Fluid Sampling System

Milburn, Hugh B.
(United States Department of Commerce/NOAA/PMEL/ Seattle)

Determination of Acoustic Signatures of Gill-Net Deployed Pingers*
Wiley, Dr. David
(International Wildlife Coalition)

Developing a Submersible-Based Suction Sampler for Marine Coarse Gravel Habitats
Wahle, Rick
(Brown University)

Development of a Low-Cost Video Camera Sled: An Inexpensive Tool for Characterizing Habitats on the Beach Haven Ridge, New Jersey*
Wakefield, Waldo
(Rutgers, The State University of New Jersey)

Development of a Novel Research Tool for Analyses of Processes Controlling Recruitment Success in Corals and Reef-Associated Fauna
Morse, Daniel E.
(University of California, Santa Barbara)

Dive Survey and Recovery of the *Monitor* National Marine Sanctuary*
Broadwater, John
(U.S. Department of Commerce, Monitor National Marine Sanctuary)

Diver Recovery of Instrument Tripod in 37 Meters of Water off Cape Hatteras, NC
Kinder, Dr. Jeff
(North Carolina State University)

Fabrication and Development of a Two-Bucket Stand-Alone Suction Sampler (TB-SASS)
Tusting, Robert F.
(Harbor Branch Oceanographic Institution)

Field Support for NURC/ UNCW Technology and Training Activities
Dinsmore, David A.
(University of North Carolina at Wilmington)

Geographic Information System Application and Development
Prisloe, Sandy
(Envirographics)

Hugo: Hawaii Undersea Geo-Observatory
Dunnebier, Fred
(University of Hawaii)

Hydrothermal Plume and Diffuse Flow Imaging Sonar System: Test and Application
Rona, Peter A.
(Rutgers, The State University of New Jersey)

***In-Situ* Gamma Spectroscopy of Loihi Vents**
Kadko, David
(University of Miami)

Integrating Advanced Acoustical and Optical Technologies to Assess Radioactive Waste Dump Sites
Babb, Ivar
(University of Connecticut - Avery Point)

NURC/MIT Stellwagen Bank National Marine Sanctuaries Cooperative AUV Survey Project*
Auster, Peter J.
(University of Connecticut, Avery Point)

Optimization of Sensors and Geopositioning Algorithms for Archival Tags
Klimley, A. Peter
(University of California, Davis)

Predictive Coastal Monitoring: Long-term Environmental Observatory (LEO-15)*
Von Alt, Christopher
(Woods Hole Oceanographic Institution)

Program Development

Assistance for a Submersible-Based Suction Sampler for Marine Coarse Gravel Habitats
Tusting, Robert F.
(Harbor Branch Oceanographic Institution)

Recovery of Hydrophone Mooringsin Monterey Canyon*
Starr, Richard M.
(Moss Landing Marine Laboratory)

Recovery of Lost ADCP in Support of Coastal Processes Studies
Lewis, Dr. Quentin
(Duke University)

Recovery of Monitoring Equipment From Gas Hydrate Beds in the Northern Gulf of Mexico
MacDonald, Ian R.
(Texas A&M University at College Station)

Recovery of Underwater Arrays in Support of DOE Ocean Margins Program
Kinder, Dr. Jeff
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Remote Environmental Monitoring Unit(s)*
Von Alt, Christopher
(Woods Hole Oceanographic Institution)

Safety Inspection of R/V *KOK*
Malahoff, Alexander
(University of Hawaii)

Sea Trials for MAXROV, the *Kraken*
Donaldson, Paul L.
(University of Connecticut, Avery Point)

Transport Monitoring Using the Bermuda-New Jersey Seafloor Cable
Larsen, Jimmy C.
(United States Department of Commerce/NOAA/PMEL)

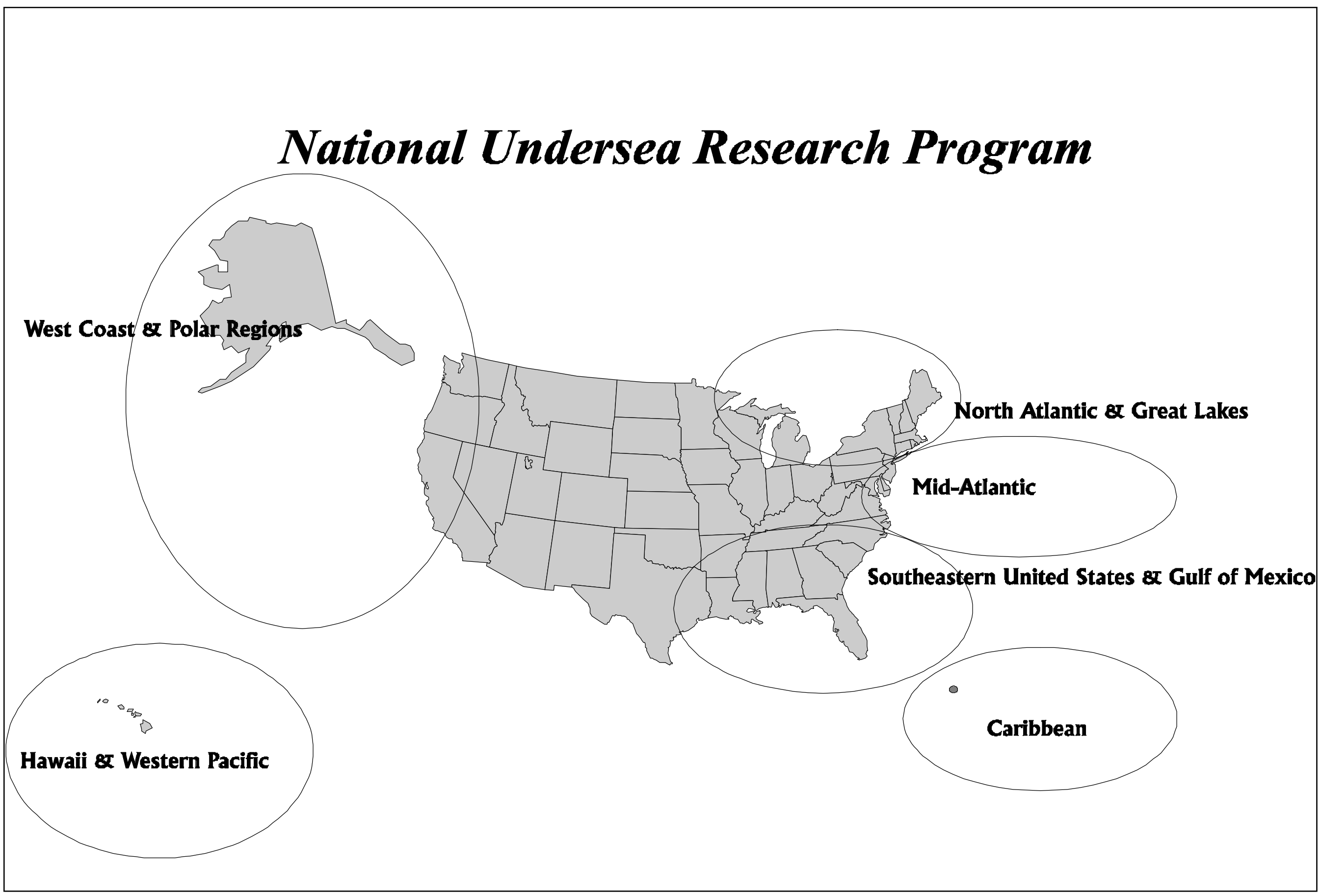
Appendix II

NURP

NURP's mission is to increase knowledge essential for the wise use of oceanic, coastal, and large lake resources through advanced undersea exploration, sampling, observation, and experimentation.

As a comprehensive underwater research program, NURP places scientists underwater, directly through the use of submersibles, underwater laboratories, and wet diving, or indirectly by using remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs), and observatories. This *in situ* (in place) approach allows acquisition of otherwise unobtainable observations, samples, and experimentation.

Since its inception, NURP has provided *in situ* support to scientists based upon the results of a competitive review process implemented by its regional undersea research centers located principally at major universities and headquarters office based at NOAA's Silver Spring, Md., location.



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